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NOTICE

The results of the OAST Space Technology Workshop which was held at Madison College, Harrisonburg, Virginia, August 3 - 15, 1975 are contained in the following reports:

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VOL I DATA PROCESSING AND TRANSFER

VOL II SENSING AND DATA ACQUISITION

VOL III NAVIGATION, GUIDANCE, AND CONTROL

VOL IV POWER

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VOL VI STRUCTURE AND DYNAMICS

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Office of Aeronautics and Space Technology

Summer Workshop

August 3 through 16, 1975

Conducted at Madison College, Harrisonburg, Virginia

Final Report

BASIC RESEARCH PANEL

Volume X of XI

OAST Space Technology Workshop

BASIC RESEARCH PANEL

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SUMMARY OF THE FINAL REPORT
OF THE BASIC RESEARCH WORKING GROUP

OAST WORKSHOP, AUGUST 1975

The Basic Research Working Group (BRWG) of the OAST Technology Workshop reviewed the source data provided by the user group, surveyed the available documents such as the Outlook for Space, the 1973 NASA Mission Model, and filtered past OAST funded studies on possible basic research experiments using the space transportation system and based on these, identified research and technology program candidates which satisfied the payload and planning objectives outlined by the Steering Committee of the Workshop.

A two-fold task was adopted by the BRWG: First, in the role of a user group, to examine potential basic space research experiments and to decide on a list of those which met certain criteria; then, in the role of a discipline group, to attempt to delineate the basic research needs of OAST to enable the space missions outlined by the user group.

Experimental areas as well as specific experiments were selected by the BRWG from past OAST studies on possible basic research experiments using the space transportation system. The justifications for the selection are (1) these experiments use the unique properties of the shuttle environment, and (2) these experiments cannot be performed on earth.

A set of recommendations was also formulated by the BRWG as a result of examining its "user needs", i.e., those items which are experiment enabling.

In order to fulfill its second important function at the workshop of providing a basic research view of NASA's program, the BRWG compiled research requirements from a variety of sources. Basic research needs from each of the other discipline groups were solicited and categorized. Mission-driven basic research requirements were examined and ranked based on inputs from the user group. Finally, four opportunity-driven basic research areas were identified from the scientific and technological background and knowledge provided by the BRWG. The four basic research areas in quantum electronics, cryogenic system technology, superconducting devices and detectors and photo-induced reactions recommended by the BRWG were considered to offer NASA the greatest potential for intermediate and long range mission benefit and which warrant particular research attention.

In conclusion, the BRWG further recommends that a mechanism be evolved to insure timely synthesis of user needs into future basic research areas of OAST on both research working and management levels.

INTRODUCTION

NASA researchers, in concert with scientists from the academic community, have been focusing attention on the use of the space transportation system as a vehicle for conducting basic research. The primary thrust of these discussions has been the identification of experiments of high scientific merit which can benefit from being conducted in the unique environment offered by space. The latter refers to the convectionless conditions available in reduced gravity, the virtually unlimited pumping capacity available, as well as the upper atmosphere temperature, composition, and radiative characteristics.

The results of these past studies were surveyed by the Basic Research Working Group (BRWG) at the OAST Space Technology Workshop. Experimental areas in fluids, combustion, low density gases, simulation, and gravity were consequently identified. The exercises involved in identifying fertile areas for experimentation were also productive in terms of recommending *modus operandi*. These experimental areas, as well as specific experiments are described along with its justifications for the need to go into space and potential applications of the science to be generated. A modular philosophy in which classes of experiments are serviced by a single facility, the involvement of as many scientists as possible from outside NASA, and the time issuance of announcement of flight opportunity are the most important of these suggestions. A set of recommendations considered as the key to facilitate the maximum utility of the space shuttle system as a basic research tool was also provided.

With potential basic research experiments to be performed in space identified, the BRWG then attempted to determine the basic research areas which OAST must emphasize so as to eventually produce the technology necessary for the missions planned by NASA. Three types of basic research requirements were compiled with inputs from the other discipline groups at the workshop, the user group and the BRWG itself. The first type of research requirements include research in areas not covered by any of the working group, but perceived by the submitting group to impact their programs; research which covers more than one discipline; research of a longer range than covered by the group; and a working group's entire research plan, which therefore appear in some form in that group's report. The second type is the mission-driven research requirements for the mission oriented users. The last type of research requirements from within the BRWG was considered as the most important output of Basic Research Working Group. It consisted of four opportunity-driven research areas which were believed to offer the most significant possibilities for "breakthroughs" and technological fallout and thus deserve special emphasis in the OAST long range basic research plans. The BRWG from their past experience and within the forum provided by the workshop further recommends

that a mechanism be evolved to insure timely synthesis of user needs into future OAST programs for mutual benefits.

PROLOGUE

In order to aid in the future development of the OAST overall space technology programs, an in-house OAST Space Technology Workshop was held at Madison College, Harrisonburg, Virginia, August 3-16, 1975. The steering group, composed of the Directors of the OAST technology divisions and chaired by the Deputy Associate Administrator for Space, charged the participants with meeting certain payload and planning objectives. For payloads these were 1) to identify specific technology areas where the utilization of Shuttle for experiments in space could significantly enhance the quality of research, and 2) to identify specific space experiments which would use the research facilities made possible by the Shuttle, Spacelab, and Interim Upper Stage. The planning objectives were to 1) formulate OAST Technology plans that reflect recommendations from the "Outlook for Space," and other pertinent sources, and 2) to incorporate these plans into specific OAST technology program goals and objectives. Ten technology groups, including the Basic Research Group, reviewed all source data and identified research and technology program candidates which satisfied these workshop objectives. The source data, i.e., the "mission needs," was supplied by the user group, consisting of various Headquarters and Center personnel associated with the Office of Applications, Office of Space Science, Office of Manned Space Flight and Office of

Tracking and Data Acquisition. In addition, information on the "Outlook for Space," and the Shuttle and Spacelab operation and payload recommendations were given in a series of lectures. Certain assumptions were made to serve as boundary conditions for the technology groups. These included 1) that aeronautics would not be considered, 2) that all missions listed in the 1973 NASA Payload Model and Volume 2 - Outlook for Space, were to be considered viable, and 3) that the costs of recommended experiments and programs not be considered at this time.

Based upon this background, and informative guidance from Carl Schwenk, the Basic Research Working Group (BRWG) adopted a two-fold task at the workshop. The first was, in the role of a user group, to examine potential basic research experiments to be performed in space and to decide on a list of these which met certain criteria. The second was, in the role of a discipline group, to attempt to delineate the basic research needs of OAST to enable the space missions outlined by the users group.

For a few years now, OAST has been funding studies on possible basic research experiments using the space transportation system. This has resulted in concepts derived internally and externally, for example in topical conferences. Based on these inputs, we carefully examined these experiments to insure that they 1) are research "in space" (i.e., using

the unique properties of the shuttle environment) as opposed to the "on space" experiments contemplated by the user group, and 2) are experiments that indeed need this environment and cannot be performed on earth.

The result of this filtering process has shown the following experimental areas to be viable: fluids, combustion, low density gases, simulation, and gravity. In every case there is, of course, an overriding basic research interest associated with the area. In addition, some experiments will also have direct and immediate technological "fallout" into the mission program needs. One such area, which has been extensively investigated, is Fluids. Here the absence of gravity will have significant effects and the experiments will test and perhaps modify or extend existing basic theory. But, certainly, these results will be of immediate use to the missions requiring cryogenic (especially superfluid helium) cooling, to those contemplating space processing (such as levitated metals refining), and to those missions involving meteorology (such as the cloud physics mission). The combustion experiments should provide considerable insight into the adequacy of present theories whose predicted results are frequently completely masked by gravitational (buoyancy) effects. In the area of low density gases, the highly directed atomic species, yet almost infinite pumping speed, available at shuttle altitude will allow research in surface interactions and free jet expansions. Another interesting research area

examined by the BRWG was the possibility that the zero-g environment will allow simulation experiments, for example, of large scale circulation processes which occur in the atmospheres of the earth and other planets, in the outer regions of the solar atmosphere, and in the earth's oceans and fluid core, to be carried out which are impossible to perform in the symmetry destroying one-g environment of the earth-based laboratory. Finally, we examined possible gravitational wave experiments.

These experimental areas, as well as specific experiments, are discussed fully in the body of the report. In addition, the BRWG also examined its "user needs," i.e., those items which are experiment enabling. These have been formulated as a set of recommendations. Briefly, they emphasize the need for: 1) experimental modules, 2) possible remote operation of experiments by ground-based scientists, 3) general purpose Spacelab facilities, 4) environmental mapping of Spacelab prior to experiment placement, and 5) environmental monitoring during experiment execution.

As stated earlier, the second aspect of the BRWG's activities was to attempt to determine the basic research areas which OAST must emphasize so as to eventually produce the technology necessary for the missions planned by NASA. To accomplish this we obtained inputs in various ways. The first was a solicitation of basic research needs from each of the other discipline groups. Approximately 50 were received, condensed

and included in the report. The response types received were 1) research not covered by any working group, 2) research which crosses the boundaries between two groups, 3) research which is necessary for missions farther in the future, and 4) entire research plans. Particularly intriguing ideas were examined more closely by one-on-one meetings and, in some cases, joint meetings between our groups.

The working group discipline needs were found to generally fall into the categories of materials, surface contamination, fluids, life support, and instrument development.

The second class of inputs was that obtained from the user group. This consisted of their detailed booklet of mission needs, the 1973 Mission Model, the various volumes of Outlook for Space, and other written material. Of equal importance were the detailed discussions with the members of the user group and specific mission managers.

These inputs allowed us to examine the mission-driven basic research requirements and rank them by various criteria. If one adopts a cost effectiveness approach, that is to rank the research areas by the frequency of application to the missions, the following list is obtained:

*Quantum Electronics: Lasers and Optoelectronic Devices

*Cryogenic Systems Technology: Superfluid Helium and Normal Cryogenics

*Superconducting Quantum Devices and

Detectors

Remote Sensing

Nuclear

*Photo-Induced Reactions

Fault Tolerant Theory

Artificial Intelligence

Solar-Electric

Failure Physics

*Bioengineering

Software Research

As a final input to the process, the BRWG examined these areas to determine which offered the most significant possibilities for "breakthroughs" and technological fallout. In other words, which are the opportunity-driven research areas again keeping in mind the ultimate mission needs? After much deliberation, the BRWG concluded that the first four areas identified by asterisk satisfy this second criterion and deserve special emphasis in the OAST long range basic research plans.

It should be stated, however, that it was not the task of this group to examine the magnitude, in manpower and finances, of this emphasis. Also, the expertise of the group was not all-inclusive; it would be advisable to repeat this analysis, with the same or other pertinent guidelines, to uncover any inadvertent omissions.

Finally, it was apparent to the members of the BRWG during the course of the workshop that the excellent interchange there between the users and basic research scientists needs to be maintained. That is, how can the user needs best be made known to, and incorporated into, the basic research areas of OAST? Similarly, how can the results of certain basic research efforts be recognized as satisfying a user's need and be turned quickly into mission-applicable technology? We were unable to develop a workable plan to answer these important questions. Suffice it to say that we recommend that further serious study be made of the problem.

I. SCIENCE EXPERIMENTS IN SPACE OVERVIEW

NASA researchers, in concert with scientists from the academic community, have for some time been focusing attention on the use of the Space Transportation System as a vehicle for conducting basic research. The primary thrust of these discussions has been the identification of experiments of high scientific merit which can benefit from being conducted in the unique environment offered by space. The latter refers to the convectionless conditions available in reduced gravity, the virtually unlimited pumping capacity available, as well as the upper atmosphere temperature, composition, and radiative characteristics. A distinction is then drawn between these investigations, referred to as "in" space experiments, and those pointed to a better understanding of space itself, termed "on" space experiments.

Of prime concern in the process of identifying experiments has been the requirement of a strong need for testing in space. It has been considered essential that justifications be constructed which clearly satisfy this requirement. In other words, thorough consideration has been given to using alternatives such as simulations, drop towers, and aircraft flight, and to presenting a clear case for space experimentation. For many experiments, in fact, it has been found that the use of these ground-based facilities has proved the need for space testing, as well as provided valuable experiment design

information.

The exercises involved in identifying fertile areas for experimentation were also productive in terms of recommending *modus operandi*. A modular philosophy in which classes of experiments are serviced by a single facility, the involvement of as many scientists as possible from outside NASA, and the timely issuance of announcements of flight opportunity are the most important of these suggestions.

The following parts of this section of the report are comprised of descriptions of identified experiments. Organizationally the experiments are segregated by science discipline. The descriptions contain justifications for the need to go into space and potential applications of the science to be generated. The section closes with a set of recommendations which the working group believe are key to facilitate the maximum utility of the space shuttle system as a basic research tool.

A. EXPERIMENTAL AREAS

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1. FLUIDS

The aspect of the Shuttle environment that has perhaps the most far reaching consequences for macroscopic physical phenomena is the absence of gravity. In weightlessness, fluids behave in an unfamiliar way. Liquid drops float freely, gas bubbles in liquids stay put, and, less obviously, there is an absence of convection. The advent of Shuttle holds the promise of opening a whole new area of research in fluids.

While many fluids scientists quicken to this opportunity, other scientists are justifiably skeptical, pointing out that phenomena in fluid physics cannot be anything but continuous and smooth functions of gravity. This argument could have been used when, early in the century, Kamerlingh-Onnes lowered temperature to near zero - but he discovered that behavior in the electrical conductivity of certain metals and the thermal conductivity of liquid helium were not continuous. He discovered two phenomena which roughly 70 years later are being richly discussed at this workshop as important technologies for space. These phenomena are, of course, superconductivity of metals and superfluidity in helium; Kamerlingh-Onnes won the Nobel Prize for this work.

In the experiments below, where gravity goes to zero, no effects quite as dramatic are expected. Nevertheless, use of space is proposed to perform scientifically interesting, im-

portant, and even exciting fluid physics experiments that can test theories hitherto inaccessible to experimental challenge, and that have broad applicability to many disciplines, ranging from nuclear physics to astrophysics. In addition, the experiments support earth-based and space-based technology and manufacture.

These experiments are discussed under individual areas of research in space:

- Drop and Bubble Dynamics
- Superfluid Helium
- Convection
- Hydrodynamic Instability
- Multiphase Phenomena (Foams and Aerosols)
- Phase Transitions at the Critical Point
- Two Phase Heat Transfer

DROP DYNAMICS

Introduction

The drop dynamics experiments to be performed on Spacelab will utilize the unique zero-g environment provided by space flight to quantitatively investigate the dynamics of a free drop. Aside from its fundamental academic interest, understanding of the behavior of free drops and bubbles will contribute to the sciences of nuclear physics, chemical processing, material processing, meteorology, and the technology of fluid management in weightlessness. The breadth of this contribution was recently underscored by the wide scope of the program presented at the International Colloquium on Drops &/ Bubbles held in Pasadena in

1974. This type of experiment is such a natural candidate for implementation in a manned earth satellite that astronauts have already, on their own initiative, carried out limited qualitative experiments of this kind. The proposed experiments aim at obtaining precise data on the behavior of liquid drops by means of high resolution cinematography in three orthogonal views. A more detailed description of the experiments is given in the following pages.

The theory of the dynamics of a free drop has been well-studied in the approximation that dynamic quantities deviate linearly from a resting drop. There is virtually no non-linear theory of the dynamics of a fluid drop. Not only are definitive experiments for the large amplitude behavior of fluid drops lacking but there is a lack of definitive experiments even for linear behavior. This is a consequence of the limitations involved in conducting experiments in an earth laboratory. Among these limitations are insufficient droplet sizes for accurate observation, limited available time for experiments, and perturbing effects due to the method of suspending the droplets.

The results of the Spacelab experiments will be used to verify existing theory, and to provide the necessary insight for further theoretical development of this subject.

Among the areas which may be illustrated by these experiments are:

- a.) Coalescence and breakup of charged droplets used as models of fusion and fission processes in nuclei.
- b.) Deployment of liquid drops from nozzles and subsequent droplet dynamics involving oscillations and droplet breakup and coalescence. Such mechanics are of fundamental importance in the design of many types of fluid reactors used in the chemical processing industry.
- c.) Stability of liquid drops under the sole influence of surface tension, required for containerless processing of molten material on earth and in space.
- d.) Competitive processes of drop coalescence and breakup important in understanding the growth of rain drops.

It is planned to carry out these experiments in a Spacelab module designed to position and manipulate drops and bubbles in weightlessness.

DROP DYNAMICS MODULE

OAST is proposing a Drop Dynamics Module for flight on the first joint NASA - ESA Spacelab Mission (STS #7). This module, to be part of an OAST project designed and built by JPL, is tentatively scheduled for approval in September, and will later be flown routinely on subsequent Spacelab flights. Drop dynamics experiments proposed by JPL are used to provide the baseline functional requirements for the module. To ensure that

the scientific value of the experiment is timely when flown in 1980, continuing scientific development of the experiment is also part of the project. In addition, the project will help manage a team of experimenters ultimately selected by NASA to perform experiments in the module.

The drop dynamics experiments to be performed in the first NASA/ESA Spacelab Mission are among the first to address some of the fundamental problems encountered in performing scientific investigations in a space environment, and should also stimulate innovative approaches for the successful utilization of zero-g laboratories in the future.

The heart of the module is a resonant chamber in which acoustic standing waves can be excited. The force provided by the radiation pressure of these waves can then be used to position and manipulate a liquid drop. It is important to note that radiation pressure can also generate torques which can be used to rotate the drop.

The chamber itself is nearly cubical with inside dimensions of 11.43 x 11.43 x 12.70 cm, which are the x, y and z faces, respectively. Three acoustic drivers are rigidly fixed to the center of three mutually perpendicular faces of the chamber. During operation of the chamber, each driver excites the lowest-order standing wave along the direction the driver faces.

In a resonant mode, the ambient pressure is maximum at the nodes of the velocity wave and minimum at the antinodes. Consequently there is a tendency for introduced liquids and particles

to be driven toward the antinodes where they collect and remain until excitation ceases.

Because this is a three-dimensional system with independent control on each dimension, it has a great deal of versatility. It can acoustically position a drop, and then manipulate it by, for example, inducing drop oscillation and/or rotation. The module will be used to examine:

Experiment Classes

- Rotation
- Oscillation
- Coalescence
- Fission
- Combustion
- Thermal Transport
- Magnethydrodynamics
- Surface Tension Driven Flows
- Non-Steady Flows
- Crystal Nucleation
- Simulation

Fluids

- Quantum
- Electrically Charged
- Ultra-Low Surface Tension
- Liquid Crystal
- Non-Newtonian
- Immiscible Liquids & Suspensions

Electrically Conducting

Of the many possible module experiments in the above list, the first two have been proposed for the first joint NASA/ESA Spacelab Mission (STS #7).

Rather than briefly discussing each of the experiments, the rotation experiment is singled out for detailed discussion because of the interesting history of the experiment and because of the extent and broad applicability of the associated theory. The aim of the experiment is the determination of the stable equilibrium shape of a rotating drop of fluid as a function of its angular velocity. Also of interest are the angular velocities at which there is a qualitative change of drop shape (bifurcation points) and the critical angular velocity at which the rotating drop fissions. Some of the detailed objectives of this experiment are listed below.

Experimental observation of the behavior of a rotating drop held together by surface tension goes beyond simply testing the existing theory. This theory has in fact been embedded in a grander theory which at one extreme embraces fluid masses held together by their gravity, modelling the stars, and at the other extreme embraces uniformly electrically-charged fluid masses, modelling atomic nuclei. Consequently, any deviation in the observed behavior of ordinary liquid drops from their predicted behavior would call into question the more all-embracing theory of equilibrium figures of fluid masses. Conversely, if experiments on the equilibrium figures of ordinary drops are in agree-

ment with predictions of theory, this would strongly suggest a unified theory of the dynamics of fluid masses. The observed behavior of ordinary liquid drops would then help to frame the theory of their dynamics and this theory in turn could be extended into the astronomical and nuclear realms. This is one of the ultimate aims of the rotating drop experiments.

Furthermore existing disagreements on the theory of rotating drops will be resolved by these experiments. Moreover, the very fact that these experiments have been proposed has stimulated re-examination of the existing theory; it has been pointed out that the existence of bifurcation points involving toroidal and triaxial drop shapes have never been explored. The existence of these new bifurcation points could be studied in the experiments to be performed on Spacelab.

The determination of the theory of the equilibrium shapes of rotating fluids began with investigations by Newton on the shape of the rotating earth, and the extensive theory that ensued was that of a free fluid held together by self-gravitation. In a crude attempt to verify this theory, Plateau carried out experiments in 1843 on ordinary rotating fluid drops in a neutral buoyancy tank, although such drops are held together principally by their surface tension, not by gravitation. His experiments were in rough qualitative agreement with the theory of that time, except for one remarkable difference: one of the stable configurations for a rotating drop was toroidal, not generally thought to be an equilibrium shape for

a self-gravitating drop. That it is in fact an equilibrium figure for rotating liquid drops held together by surface tension was not demonstrated until the theory of ordinary rotating liquid drops evolved more than seventy years later when Rayleigh investigated droplets symmetric about the rotation axis. The stability of the simple axisymmetric shapes awaited study by Chandrasekhar and even today the stability of the toroidal and nonaxisymmetric shapes remains virtually unexplored both theoretically and experimentally.

The Skylab experiments on rotating drops yielded the "pinched" triaxial shapes resembling a "dog-bone". In one such experiment a dog-bone shape fissioned; it was not clear if this was a result of the particular dog-bone being a "saddle-shape" or if it was a result of the dog-bone being a stable shape close to the limit of stability but with an internal flow or slight oscillation whose extra energy converted the shape to a saddle-shape once the extra energy was added to the rigid body's fluid motion.

It is very important to note that the Plateau and Skylab experiments yielded different shapes for sufficiently large angular velocity - there is no dog-bone shape demonstrated in the Plateau experiments, neither is there a toroidal shape demonstrated in the Skylab experiments. Similar discrepancies were noted in experiments on cylindrical liquid columns rotating about their axis. Neutral buoyancy experiments carried out on earth showed the instability of such columns always to

be axisymmetric, while the Skylab experiment on rotating liquid columns showed the instabilities to be nonaxisymmetric. However, the axisymmetric instabilities were recovered on Skylab once the fluid was made sufficiently viscous.

Plateau's failure to observe the dog-bone may have been due to the effect of "added mass", i.e., in the Plateau experiment a triaxial drop nonaxisymmetric about the rotation axis will entrain adjacent portions of the surrounding liquid.

In weightlessness the added mass effect becomes negligible because the ratio of the density of two fluids can be chosen to be three orders of magnitude less than unity.

Thus it appears that viscosity and virtual (added) mass effects strongly limit the validity of neutral buoyancy experiments. In fact, the effects of viscosity and virtual mass on the flows in rotating fluids may make otherwise stable shapes unstable and vice versa. These effects can be studied experimentally only in the true weightlessness afforded by space flight where the viscosity and the density differences of the two liquids can be freely chosen.

Some of the detailed objectives of this rotation experiment are the determination of the:

Bifurcation Points of a Rotating Drop

Nature of the Instability at the Bifurcation Point (Is it dynamically or secularly unstable?)

Equilibrium Shapes of Rotating Drops

Frequencies and Modes of Oscillation of Rotating Drops

Critical Angular Velocity for Drop Fission

SUPERFLUID HELIUM

Superfluidity is a universal phenomenon occurring in the submicroscopic realm of atomic nuclei as well as the astronomical realm of neutron stars and pulsars.

On earth, the liquid forms of both isotopes of helium and their solutions demonstrate superfluidity. There are several striking properties of a superfluid that can be demonstrated. These derive from the fact that superfluid helium consists of helium atoms in a macroscopic quantum state - one that spatially extends throughout the liquid.

Superfluid helium in space becomes a convenient means for studying the universal phenomena of superfluidity. To do this requires that the superfluid helium be in the form of a free drop long enough to manipulate it by rotating it and/or exciting its modes of oscillation. This demands that the experiments be performed in an orbiting laboratory such as Spacelab. In fact, it turns out that weightlessness allows other fundamental experiments to be performed on superfluid helium that are certainly impracticable and perhaps even impossible on earth.

Consequences of superfluid helium being of a macroscopic quantum state are zero viscosity, superconductivity of heat, zero entropy - causing it to flow from colder to hotter regions, and the absence of any vorticity except in the form of quantized vortices.

From these there are other extraordinary properties that

follow. Because it has zero viscosity, it can flow unimpeded through submicron holes and can exist as submicron films that cover a surface and in which the superfluid flows virtually unimpeded. Because superfluid helium is a superconductor of heat, it cannot develop "hot spots" and so doesn't boil unless subjected to extraordinary heat flux; it is a "quiet" fluid. This property along with its low temperature, less than 2.2°K, high thermal conductivity, and its tendency to seek a heat load make superfluid helium the ideal cryogen for cooling detectors of all kinds. The tendency to seek a higher temperature region may make cryogen cooling in space easier for superfluid helium than for ordinary cryogens!

Despite the fact that much is known about superfluidity, only recently has the existence of quantized vortices been demonstrated. Moreover, little is known about relatively thick superfluid helium films ("puddles"). No direct demonstration of the macroscopic wave function exists. It appears that Spacelab will allow important studies to be carried on in all these areas.

Superfluid Helium Research Experiments in Space:

- . Superfluid Helium Drop
- . Superfluid Helium Film
- . Thermodynamics
 - . Critical Point
 - . Lambda Point

- . He^3/He^4
 - . Consolute Point
 - . Ultraflow Temperatures - Refrigerators
- . Detection of the Macroscopic Wave Function

Superfluid Helium Drop Experiment:

- . Quantized Vortices - Visible
- . Dynamics of Vorticity
- . Oscillation of Vortex Array
 - . Coupling to Shape Oscillations
 - . Contradictions in Theory
 - . Pulsar Simulation
- . Temperature Waves in Rotating Drop
- . Superfluid Josephson Effect

Superfluid Helium Film Experiment:

- . Effect of Flow on Thickness and Vice Versa
- . Profile of Film - Vapor Interface
- . Capillary Waves on Film
 - . Vary g to Vary Frequency, Wavelength Independently
 - . Study Macroscopic Wave Function

Superfluid Helium Lambda Point Experiment:

- . Zero- g Allows Approach of Large Bulk to Within 10^{-9}K of λ point
- . New Properties Expected
- . Study of Macroscopic Wave Functions

Helium Critical Point Experiment:

- . Test Deviation from Law of Rectilinear Diameters
 - . Large Bulk Can Be Brought to Critical Point
 - . Critical Temperature of He Lowest of All Substances

He³/He⁴ Experiment:

- . Large Bulk Can Be Brought to Consolute Point
 - . Supercooling - New Superfluid Properties
 - . Behavior at Phase Separation - Nucleation
- . Dilution Refrigerator for Space - Ultralow Temperatures in Space

CONVECTION PHENOMENA

It is commonly thought that convection cannot occur in low gravity ($10^{-6}g$) environments and, therefore, there will be no fluid motions. This misconception about fluid flow at reduced gravity prevails for a number of reasons. Firstly, the principles governing the conditions under which any sort of natural convection is likely to occur are not well known, are not defined or are confused due to their complexity. Furthermore, non-gravity forces that could generate flows in such an environment are frequently suppressed in a normal gravitational field and are, therefore, unfamiliar. In actuality, there are a variety of non-gravity forces that can induce fluid flows in

space, including surface or interfacial tensions, thermal-volume expansions, density differences caused by phase change, and magnetic and electric fields. Gravity-induced convection also can still be appreciable even at $10^{-6}g$ under certain conditions.

An examination of convection phenomena in space will aid in the understanding of numerous terrestrial applications. Examples are the liquification of natural gas and flame spreading on liquid pools. Proper design of propellant transfer systems for space use will also require a knowledge of low gravity convection phenomena. Numerous space processing operations will also be aided by this knowledge.

Scientific Experiments of particular merit are:

- . Surface tension driven convection in reduced gravity
- . Natural convection at low gravity
- . Phase change convection
- . Thermosolutal convection
- . Electro-convection

HYDRODYNAMIC INSTABILITY

Gravitational forces are important in hydrodynamic flows involving large variations in density. The extreme case of variation is that of an interface separating a gas from a liquid. Thus, the most pronounced effects of gravity are to be expected in flows with free surfaces and interfaces, and in two phase flows. Such complex systems are subject to various

instabilities. Gravity suppresses the fundamental physical mechanisms of many of these various instabilities. For example, a recent theory concerning the spatial instability of a circular liquid jet cannot be tested on earth due to gravity-driven distortions. A zero gravity environment will allow experimental measurements which would otherwise be impossible.

A knowledge of hydrodynamic instabilities through in-space experimentation will aid in the understanding of a variety of applications, particularly in the chemical industry. Some examples of these include gas absorption processes (e.g., removal of CO_2 from exhaust gases), stripping in spray towers, (e.g., preparing industrial products such as detergents, foodstuffs, and pharmaceuticals) and droplet or capsule formation (e.g., fuel injection). Aside from the direct industrial applications, gas-liquid systems serve as models for complex phenomena such as oxygen transport into liquid systems during the manufacture of steel.

Specific experiments that should be conducted in a reduced gravity environment concern instability of a circular liquid jet issuing into fluid environment and the impingement of a gas jet on a liquid surface.

MULTIPHASE PHENOMENA

On earth, multiphase mixtures generally segregate or separate because of differences in density. In the absence of gravity, dispersions and foams are formed more readily and

are more stable with respect to segregation and separation. The spacelab offers an opportunity to study the factors controlling the formation and stability of multiphase mixtures in the absence of gravity. Particular areas of interest include foams and aerosols.

The formation, stability, and breakdown of foams are controlled by gravity and surface tension. The competing influences of these effects has made it difficult to obtain a clear understanding of the role played by either. Space experiments will make possible studies on the fundamental characteristics of foams under more controlled and stable conditions by permitting the observation of the role of surface forces in the absence of gravity.

Studies of the characteristics and behavior of aerosols and particulates in low-gravity are of interest since the persistence of dispersed liquids and solids in the atmosphere of a space vehicle may have consequences for the health and safety of the astronauts.

The behavior of aerosols and particulates will have consequences for space processing. Experiments on sintering of powders will generate dispersions of particulates, as will experiments where a condensation of reacting gases takes place. Furthermore, it may prove desirable to react materials where one is in the form of a dispersion. It may also be desirable to use inert dispersions to provide nuclei for the condensation of gaseous reaction products to prevent them from con-

densing on the walls of the reaction chamber.

PHASE TRANSITION AND CRITICAL PHENOMENA

In the critical region many thermodynamic and transport properties of fluids display an anomalous behavior. Very precise experimental measurements are required to quantify these anomalies. However, experiments under normal gravity conditions on earth can be influenced by large density inhomogeneities which occur near the thermodynamic critical point. From a fundamental viewpoint, a measure of how closely a fluid sample approaches the critical point is the long range correlation length, a statistical mechanical parameter which can be measured in every thermodynamic state of a fluid. The correlation length increases as the critical point is approached. However, because of the gravitationally produced density inhomogeneity, the correlation length cannot exceed approximately 10^{-4} cm (in the vertical direction in samples of CO_2 , for example), thus severely limiting the attainment of valid results. Under reduced gravity conditions, though, the attainment of correlation lengths of a truly macroscopic size would become possible.

Reduced gravity experiments would also provide an important new region for making observations on nonequilibrium phenomena and phase transitions. The absence of gravity upon the phase separation process which occurs in pure fluids and fluid mixtures is overwhelming. In a typical case, as the temperature of a fluid or a fluid mixture is changed to bring it into a thermo-

dynamic state in which phase separation is thermodynamically favored, inhomogeneous nucleation will occur. Since the phases are almost invariably of different densities, the earth's gravitational field will cause relative motion of the two phases. In a very short time the effects of the nucleation are felt throughout a macroscopic sample since the growth of the separate phases is aided by gravitational sedimentation of the phases into layers of differing density. In a low-g environment the rate of sedimentation will be greatly reduced and the important roles of surface and diffusional phenomena will become much more visible. The effects of inhomogeneous nucleation will not be propagated as rapidly, thus permitting homogeneous nucleation to be more readily observed.

The critical region of fluids has been shown to possess a "universal" character. Thus, the thermodynamic and transport properties in the critical region, or all pure fluids, show common dependencies on the temperature and density difference from the critical point. This "universality" implies that experimental results from the study of the properties of one fluid will be immediately applicable to the description of the properties of other fluids.

Specific experiments that initially would be of value include:

- . Visual observations of phase transitions
- . Measurement of transport properties
- . Light scattering measurements to yield the correlation length and thermal diffusivity

TWO PHASE HEAT TRANSFER

OAST has supported research programs on the behavior of two phase fluids in a space environment for over fifteen years. The application of these basic phenomena in such problem areas as propellant thermal conditioning, cryogen storage, and life support system operations has provided this interest. Although some answers have been provided, many questions have remained or even intensified. The problems of boiling and two phase flow in reduced gravity pose such questions.

In-house and contracted studies have extensively investigated gravity effects on saturated pool boiling, subcooled pool boiling, forced convection boiling, burnout heat flux, minimum heat flux, bubble growth, and bubble dynamics. Qualitative information on all these processes has been obtained within the limitations of ground based reduced gravity facilities and centrifuges. The results have been frequently inconclusive and, at best, hypothetical in their application to a long term reduced gravity environment. Work in this area has been virtually suspended until a facility capable of long term experimentation is available, such as the Spacelab.

Specific space experiments that would be of particular interest include investigations of:

- . Pool boiling
- . Homogeneous bubble nucleation and growth
- . Two phase flow

These experiments should exhibit significant gravity

effects as evidenced by the qualitative short term reduced gravity data available. Because of the similarity in requirements for these investigations, a test facility providing common power, instrumentation and data retrieval capabilities appears reasonable.

2. COMBUSTION

During calendar year 1974, OAST funded overview studies conducted by scientific experts in order to identify areas from which worthy space experiments could be drawn. Two of these overviews in the area of combustion were particularly productive. They not only identified numerous good experiments but they also suggested that these experiments were "both urgently needed and inaccessible on earth". The latter comments have obvious reference to the energy related problems which we are now confronted with and will continue to face in the years ahead.

Germane to the arguments supporting combustion experiments in space are the possibility of:

- 1). Experimentation that is inaccessible on earth.
- 2). Experimentation involving the selected coupling (and decoupling) of free convection to other transport processes.
- 3). Identification of the specific experiment roles of free convection in a wide range of combustion phenomena.
- 4). Experimentation to provide the observational bases for theoretical formulations where current theory is inadequate.

The overview studies identified broad areas within which space experiments were recommended. Several of these areas were determined to show particularly outstanding promise.

They are:

- 1). Premixed gaseous autoignition, ignition, propagation, and extinction limits
- 2). Theory of noncoherent flame propagation
- 3). Cool flames in large premixed gaseous systems

- 4). Burning and extinction of individual and clouds of drops and particles
- 5). Ignition and autoignition of clouds of drops and particles
- 6). Radiative ignition, flame spreading, burning and extinction of large solid fuel surfaces
- 7). Smoldering and its transition to flameing
- 8). Radiative ignition, flame spreading, burning and extinction of large liquid fuel surfaces
- 9). Gas jet combustion
- 10). Transient responses of flames to time-dependent gravitational fields

Specific experiments within these areas that are of particular merit are:

- . The combustion of fuel droplets in reduced gravity
- . The combustion of porous solids in reduced gravity
- . The effect of a reduced gravity environment on flammability limits in a standard tube apparatus
- . The combustion of fuel particles in reduced gravity
- . Flame spreading and steady state burning of pools of liquid fuels in reduced gravity

The rationale for selecting these particular experiments is based on both scientific and societal needs. Underlying all the studies is the theme that associated with each is a set of important theoretical questions that are currently unanswered which can be wholly or partially attributable to confusing gravitational influences, and which can potentially be answered by zero and low gravity experimental data. These studies are, therefore, substantially oriented toward the generation of information that will lead to a better understanding of physical

phenomena on earth. The value of the work is clear when one considers its application to such problems as more efficient and cleaner industrial energy sources, fire research, and combustion as applied to propulsive devices.

A particular example of the scientific rationale for this research is provided by the droplet burning problem. Measurements of droplet burning in laboratories on earth are difficult to interpret with high accuracy because of the intrusion of effects of gravity-induced buoyancy. Buoyancy in droplet combustion cannot be handled by precise mathematical theory. Therefore, engineering correlations have been used to describe burning rate and flame diameters. By contrast, precise theory can be developed within the context of the flame sheet approximation in the absence of buoyant flow. A rather thorough theory for the transient spherically symmetrical combustion of fuel droplets has recently been completed. However, one can never be certain in the absence of definitive experimental tests, such as could be provided in space, if these theories are correct. In another sense, sufficiently small droplets at normal gravity are influenced negligibly by buoyancy. However, in practice it is found that before droplets become small enough for buoyancy to be entirely negligible, effects of finite rate chemistry come into play. It is then difficult to sort out the different influences of kinetics and buoyancy which occur simultaneously. Experiments at zero gravity, by eliminating buoyancy, can provide much more ready access to the kinetic influences.

Studies of extinction of small droplets at zero gravity, therefore, are desirable for obtaining accurate overall chemical-kinetic data for the gas-phase combustion process occurring in a diffusion flame surrounding droplets.

A rationale similar to the above can be provided for the other recommended combustion experiments. Further, because of the commonality that exists in combustion experiments in terms of environment, instrumentation and procedural requirements, it would appear reasonable to provide a single module in which to carry out the investigations.

3. LOW DENSITY GASES

Spacecraft move through a low density gas composed of molecules, atoms and ions with long, mean free paths. Pressure at orbital altitudes varies from 10^{-6} torr to 10^{-12} torr and the neutral species changes from primarily molecular nitrogen, to atomic oxygen, then to helium with increasing orbital altitude. This environment permits the development of experiments which exploit ultrahigh vacuum or the atmospheric constituents.

A class of experiments which use this environment seems viable. This classification suggests a master piece of experimental apparatus, called the Molecular Beam Lab Module. Some experiments for the module are described below.

Molecular Beam Lab Module

Reaction Experiments (O, H, O₂, or N₂)

1. Colliding Beams--Reactions between an atmospheric beam and an intersecting species beamed from the laboratory are of extensive interest in chemistry. These include:
 - a. Controlled experiments on upper atmospheric chemistry
 - b. Accurate measurements of reaction energies such as ionization potential and dissociation energy
 - c. Investigation of the dynamics of reactions and tests of kinetic theory
2. Surface Oxidation--The intense flux of (normally unavailable) atomic oxygen provides a unique opportunity for oxidation experiments. Applied goals under consideration include:
 - a. The feasibility of forming oxide layers on semiconductors at ambient temperature for electronic components

- b. Studies of oxidation surface-barriers
- c. Combustion of solids (and gases) with space atomic oxygen for processing energy

Among the more fundamental studies are:

- a. Oxidation reactions between the beam and another species on the surface, to measure reactive cross-section for product species which are unstable in the gas phase.
 - b. Investigations of catalyzed oxidation and corrosion.
 - c. Diffusion of the beam species over an atomically clean surface.
 - d. Investigations of atom exchange, reactivity and phonon structure for oxide solids.
3. Reactive Sputtering--Energetic atomic oxygen and hydrogen beams offer potential for the removal of surface layers. This is an unexplored area with possible application for space manufacturing.

FREE JET EXPANSION EXPERIMENTS

Study of Free Jet Expansions (FJE) is fundamental research with strong ties to applications. The primary interest is to develop basic information on final thermodynamic states of expanded gases to support gas release experiments proposed for atmospheric and space science. Non-NASA application relates to commercial processes. FJE experiments are limited on the ground by available vacuum pumping speed and the small scale of important effects.

- 1. Nonequilibrium Thermodynamics--Gas expansion begins from a well-characterized continuum fluid state. During the free expansion, the gas develops a streaming pattern and cools. Finally, gas density drops to where intermolecular inter-

actions cease and a stable nonequilibrium state exists.

Experiments will focus on temperatures characterizing the non-interacting energy modes, translation, vibration and rotation. These characterize the final state of the expanded gas before it interacts with other species.

2. Binary Collisions--Fundamental measurements of binary collision cross sections related to each of the above modes will be valuable for interpretation of interactions between the expanded gas and the ambient atmosphere, and for understanding atmospheric and gas phase phenomena.
3. Entrainment and Slippage--Entrainment involves the transfer of momentum from one beam to another and the resulting direction change. Slippage pertains to a species which attains a speed less than the jet speed. These differences in speed or momentum may be used to improve particle size measurements, isotope separation or enrichment.

Beams and Environment Characterization

1. Beam--A beam originating from the space atmosphere must be monitored continuously since the density and composition of the atmosphere varies with location, season and other variables.
2. Contamination--The space atmosphere will be contaminated by attitude control gas, water dumps, outgasing products and other shuttle activities. An atmospheric beam must be monitored for contamination and may be used to map the contamination cloud around the shuttle.

4. SPACE FLIGHT SIMULATION OF LARGE SCALE PHENOMENA

This section describes one identified example of a potentially larger class of flight experiments to model important large scale physical phenomena in experiment configurations whose symmetries are fatally disturbed on earth by gravity or other unavoidable influences. Thus these types of experiments would require a steady state zero gravity environment for their operation. The example concerns the fluid dynamics of astronomical bodies.

The large scale circulation processes which occur in the atmospheres of earth and the other planets, in the outer regions of the solar atmosphere, and in the earth's oceans and fluid core are of great scientific and practical interest, yet many features of such flows are impossible to properly simulate in the laboratory in one-g. Physically all of these systems consist of a spherically symmetric fluid shell of rotating fluid with thermal driving forces in a radial gravitational field. For various planetary situations the heating of the fluid may be independent of latitude and longitude, longitudinally varying or, in the case of Jupiter, longitudinally varying at the outside and uniform at the surface. Many of the observed large scale features present in the circulations on these bodies are thought to be related to the interaction of thermally or buoyancy induced motions in the latitude dependent Coriolis force. Thus rotational and gravitational forces are major constraints on the flows, but it also appears that

the spherical nature of the astronomical bodies plays a very decisive role.

For example, possibly the most important of the many observed planetary circulation features is the equatorial accelerations of fluids. All of the theories which attempt to explain these accelerations require differential rotations which can in turn be explained by the latitude dependent Coriolis force. Many other observed flow features have been treated analytically. However, because the flows being modelled are three-dimensional, time-dependent, and range over many length scales, simplifications and unrealistic assumptions are required for even the most sophisticated computer analyses.

Conversely it has proved impossible to model the sphericity of the astronomical bodies properly in the laboratory over anything more than a few degrees in latitude, which prevents observation of the most interesting effects.

In the laboratory spherically symmetric apparatus has been constructed in which the radial gravitational field is simulated by electric fields. However, even for relatively high electric fields, the real unidirectional gravity field destroys the simulated symmetry and permits large distortions in the fluid flows. Attempts to make the simulated radial gravity much greater than the real field fail due to voltage breakdown.

The space experiment would consist of a cell a few centimeters in diameter which could be operated in association with its own module or another module, such as that for fluid

physics. The cell would consist perhaps of an inner spherical conductor, an outer transparent conducting shell, and a dielectric fluid between the two. A properly scaled, but relatively weak, electric field between the two shells would simulate the radial gravity. The apparatus would be mounted on a rotating table, such as that included in the Shuttle laboratory as a general purpose rotating table/low-g centrifuge, to impart the proper scaled rotation rate. Thermal inputs to the fluid would be via heaters, lasers, etc. Finally fluid motions might be monitored with high temporal and spatial resolution by laser scatter spectroscopy or schlieren techniques.

The above is an example to illustrate the potential value of a space experiment facility to permit the simulation of highly realistic scaled systems representing important large scale phenomena. Other specific problems than the fluid dynamics of astronomical bodies cited above certainly exist and should be actively sought out.

5. GRAVITY

One of the most controversial and striking predictions of the general theory of relativity is that of the existence of gravitational radiation. While theoreticians have finally come to agree that such radiation does exist, experiments claiming to demonstrate its existence are questioned.

Unlike most tests of general relativity, demonstration of the existence of gravitational waves is different since it is a dynamic test rather than a static one. One of the primary difficulties in the detection of such radiation is that gravity appears to be the weakest force in the universe. Consequently, gravity wave detectors must be extremely sensitive and noise-free.

Recently the Russian physicist, Braginski, has pointed out that large single crystals of sapphire can be used as a gravitational wave antenna that has an intrinsic sensitivity that is 10^{13} greater than those previously used. Weber has suggested that by flying such an antenna in the isolation of space, noise can be appreciably reduced, offering the real possibility of successfully detecting gravitational radiation.

One of the ideas is to isolate an earth orbiting antenna from the forces of magnetic fields, electromagnetic fields, and mechanical vibration by enclosing it in a superconducting shell. To provide acoustic isolation the antenna itself would be coated with a superconducting film allowing it to be levitated within the shell. Moreover, since flux within the shell is

fixed, the oscillations of the antenna induced by gravitational radiation would alternately compress and vary the magnetic flux between the antenna and shell resulting in an extremely small oscillating magnetic field which nevertheless could be detected by means of a superconducting SQUID magnetometer. Such a "contactless" readout would maintain the isolation of the antenna neither spoiling its intrinsic sensitivity nor generating noise.

Burke has pointed out, however, that unless the position and orientation of the antenna is maintained with extreme accuracy, gravity gradients of the earth and even the sun, generate signals which can mask the signal of gravitational radiation. However, it appears that the frequency of such gravity gradient signals can be discriminated against either directly or by coincidence techniques using a second antenna. All these considerations are now under study.

B. WORKING GROUP RECOMMENDATIONS

B. WORKING GROUP RECOMMENDATIONS

After digesting the identified experiments, considering the opinions of involved scientists as voiced through committee members, and drawing on their own expertise, the working group has formulated a set of recommendations which it believes very important.

1. MODULAR APPROACH/USER GROUPS/AO's

Examination of the identified experiments reveals the possibility of several groupings in terms of testing requirements. That is, a commonality exists in terms of environmental, instrumentation, data retrieval, and procedural requirements such that a class of experiments can be defined. This grouping suggests the use of modules that would serve these common needs. In the construction of these modules, however, it is imperative that the needs and requirements of potential individual experimenters, or users, be solicited. It is only through the combination of a modular philosophy and direct user participation in the modular design that this concept can prove to be a cost benefit. This timely requirement for user participation further necessitates the issuance of announcements of flight opportunity, AO's, at an early date. A user or peer group should be appointed for each module, the members most likely consisting of those expert scientists (both within and outside NASA) who assisted in the module design, to decide on the appropriate experiments. This concept is similar to that used on national facilities such as

particle accelerators.

We strongly recommend that modules be constructed to service the needs of classes of experiments, that user participation in module design be effected, that AO's be issued to the scientific community at an early date, and that a user group be assigned to each module.

2. PROVISIONS OF GENERAL PURPOSE FACILITIES

Many of the experiments have defined requirements that are beyond what would be included in a module. These requirements fall in a broad category of what can be termed general purpose facilities. These include (1) a low gravity centrifuge, (2) a He^{II} dewar, and (3) a mass measuring device. A low gravity centrifuge will permit experimentation in reduced gravity environments that fall in the range $0 < g < 1$. Testing in this range of gravity levels will permit gravity dependent predictions to be systematically constructed from validated zero gravity analyses. The He^{II} dewar is a necessity in order to conduct several experiments that have been identified on droplets and films. In addition, this dewar could be utilized in other planned missions. Finally, there is a requirement for the measurement of small mass changes ($\sim 1\text{gm}$) with high accuracy. For example, some combustion experiments will require a measurement of mass changes during the burning process.

We strongly recommend that steps be taken to develop a low gravity centrifuge, a He^{II} dewar, and a mass measuring device

for use on board the Space Shuttle.

3. POSSIBILITY OF REMOTE OPERATION OF SHUTTLE EXPERIMENTS

The National Academy of Science has recommended that science-on-space experiments on Shuttle be accomplished by principal investigators operating their experiments remotely from the ground.

This in no way implies that mission and payload specialists are not required. However, experience and analysis has shown that astronaut timeline is the most critical resource for manned missions. Remote operation of some experiments would allow the astronaut to attend to the maintenance and servicing of experiments while concentrating on one or two which are in his area of expertise. Furthermore, remote operation saves investment in the training of the astronaut to do complicated experiments or outside his area of expertise, or the investment in training investigators to fly.

Because of the many conveniences to the investigator, remote operation of experiments would increase use of the Shuttle. In addition, entire teams of ground operators could participate in a series of related experiments.

Bandwidth is a problem in the two-way communications with Shuttle which remote operation of experiments would require. A possible solution would be to multiplex individual experiment communication channels. A long term solution may be the use of a laser communication link.

A judgment is required as to which is more important for Shuttle--cost savings allowed by reducing bandwidth or stimulating the use of Shuttle by many investigators, and thus fulfilling NASA's promise of heavy use of Shuttle.

We recommend that provision be made in the Shuttle to allow the principal investigators to operate their experiments remotely from the ground.

4. ENVIRONMENTAL MAPPING

The working group has examined these space shuttle experimental conditions which could present difficulties to the conduct of the experiments outlined above. Inputs to these examinations have included the concerns expressed by scientists attending conferences on potential physics and chemistry experiments in space, and the Spacelab report presented at the current workshop. It is clear that certain phenomena, for example critical point effects, can be significantly altered by charged particles such as primary or secondary cosmic rays. Similarly, this charged particle stream may interfere with charged droplet and cloud physics experiments. Solar flares, with their attendant radiation burst, may have similar effects. Noise levels, either electromagnetic or acoustic, could present considerable experimental difficulties, for example, in data acquisition. Unsteady perturbations of the gravitational field, called "G-jitter," can arise from space craft orientational stability and mechanical vibrations. Since some experiments will be nullified by a

jitter small as $10^{-3}g$, this is also a concern. These concerns have led the working group to the following recommendation:

We strongly recommend that further research be devoted to predicting and measuring the cosmic ray levels, the solar flare radiation, the electromagnetic and acoustic noise levels, and the G-jitter as a function of position in the shuttle laboratory environment. Such environmental mapping will be extremely cost effective in eliminating certain possible experiments or in clearly defining *a priori* the optimum location of an experimental module.

5. ENVIRONMENTAL MONITORING

Consistent with the above considerations in (4), it is clear that those phenomena which are of a transitory nature may occasionally affect an experiment during its execution. In order for the investigator to properly analyze his data and interpret that taken during such a transient disturbance, the working group reached the following:

We strongly recommend that a standard set of diagnostic instruments be included as onboard shuttle equipment which provides a time log of the environmental factors mentioned in the prior recommendation.

APPENDIX 1. LIST OF EXPERIMENTS

A. Combustion

1. Single Fuel Droplets
 - a. Ignition
 - b. Steady State Burning
 - c. Extinction
2. Clouds and Arrays of Fuel Droplets
 - a. Autoignition/ignition
 - b. Steady State Burning
 - c. Extinction
3. Premixed Gases
 - a. Autoignition/ignition
 - b. Flame Propagation
 - c. Extinction Limits
4. Gas Jets
5. Single Fuel Particles
 - a. Ignition
 - b. Steady State Burning
 - c. Extinction
6. Large Solid Surfaces
 - a. Radiative Ignition
 - b. Flame Spreading
 - c. Steady State Burning
 - d. Extinction
7. Clouds and Arrays of Fuel Particles
 - a. Autoignition/Ignition
 - b. Steady State Burning
 - c. Extinction
8. Large Liquid Surfaces
 - a. Radiative Ignition/Source Ignition
 - b. Flame Spreading
 - c. Steady State Burning
 - d. Extinction

B. Fluids

1. Super Fluid Helium Drops
 - a. Quantized Vortices--Visible
 - b. Dynamics of Vorticity--Generation and Destruction
 - c. Oscillation of Vortex Array and Coupling to Shape Oscillations
 - d. Temperature Waves in Rotating Drop
 - e. Josephson Effect
 - f. All Experiments Listed Under Drop Dynamics

2. Super Fluid Helium Films
 - a. Effect of Flow on Thickness and Vice Versa
 - b. Profile of Film-Vapor Interface
 - c. Capillary Waves or Films
 - d. Vary g to vary frequency, wave length
3. Superfluid Helium - Lambs Point
 - a. Transport and Thermodynamic Properties
 - b. Determine Coherence Distance - Study of Macroscopic Wave Functions
4. Helium - Critical Point - Test Deviation of Law or Rectilinear Diameters
5. He^3 / He^4
 - a. Properties of Supercooled - Superheated Solutions at Consolute Point
 - b. Phase Separation - Nucleation at Consolute Point
 - c. Ultralow Temperatures - Rotating Dilution Refrigerator
6. Phase Transition and Critical Phenomena
 - a. Visual Observations
 - b. Measurement of Transport Properties
 - c. Light Scattering Measurements
7. Multiphase Phenomena
 - a. Foams-Formation, Stability and Breakdown
 - b. Dynamics of Aerosols
8. Two Phase Heat Transfer
 - a. Pool Boiling
 - b. Homogeneous Bubble Growth and Dynamics
 - c. Two Phase Flow
9. Hydro Dynamic Instabilities
 - a. Liquid Jets
 - b. Gas Jet - Liquid Surface Interactions
10. Convection Phenomena
 - a. Surface Tension Driven Flows
 - b. Natural Convection at Low Gravity
 - c. Phase Change Convection
 - d. Thermal-Solutial Convection
 - e. Electro-Convection
11. Rotation of Drops and Bubbles
 - a. Shape
 - b. Values of Bifurcation Points
 - c. Type of Instability at Bifurcation Points
 - d. Hysteresis and Dynamics at Bifurcation Points
 - e. Critical Angular Velocity for Fission

12. Large Amplitude Oscillations of Drops and Bubbles
 - a. Frequency
 - b. Damping
 - c. Shape
 - d. Mode Coupling
 - e. Coupling or Oscillations and Internal Flow
 - f. Shape - Bohr Wheeler Saddle Points
 - g. Minimum Energy for Fission
 - h. Aperiodic Motion
13. Coalescence of Drops and Bubbles
14. Thermal Transport in Drops and Bubbles
15. Surface Tension Driven Flows in Drops and Bubbles
16. Non Steady Flows in Drops and Bubbles
17. Crystal Nucleation in Drops

C. Simulation

- a. Atmospheres and Ocean Flows
- b. Solar and Earth Core Flows
- c. Solar Particle - Magnetosphere Interaction (Terrella)

D. Low Density Gases

1. Colliding Beam Reactions
 - a. Association Ionization
 - b. Rearrangement Ionization
 - c. Electron Transfer
 - d. Polar Dissociation
 - e. Penning Ionization
 - f. Hydrogen Atom Abstraction
 - g. Addition Reactions to Organic Molecules
 - h. Chemiluminescent Reactions
2. Surface Reactions
 - a. Semiconductor Oxide Layers
 - b. Oxidation Surface-barriers
 - c. Three Body Oxidation
 - d. Catalyzed Oxidation
 - e. Surface Diffusion
 - f. Atom Exchange, Reactivity and Phonon Structure
3. Reactive Sputtering
4. Free Jet Expansion
 - a. Non-equilibrium Thermodynamics
 - b. Binary Collision Cross Sections
 - c. Entrainment and Slippage

E. Gravity

APPENDIX 2. TECHNOLOGY REQUIREMENTS

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 1

1. TECHNOLOGY REQUIREMENT (TITLE): Experiments in a PAGE 1 OF 3
Large-Scale-Phenomenon Simulation Lab Module

2. TECHNOLOGY CATEGORY: _____

3. OBJECTIVE/ADVANCEMENT REQUIRED: To perform a series of realistically
scaled experiments in a low gravity module to simulate important very large
scale planetary, solar and other phenomena.

4. CURRENT STATE OF ART: Some ground experiments have been performed with
limited success due to the inability to simulate proper symmetries in a 1-g
field. HAS BEEN CARRIED TO LEVEL _____

5. DESCRIPTION OF EXPERIMENTS

The dynamical processes in planetary and solar atmospheres, and the earth's oceans and fluid core, will be simulated in a spherically symmetric apparatus in this module. Flow processes will be measured in an annular region of dielectric fluid subject to a perfectly radial electric field (simulating gravity), to rotation, and to various thermal inputs. Flows in real time on a microscopic scale will be determined by laser scattering spectroscopy, Schlieren techniques, and others.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

A number of theories have been advanced to explain many flows which have been observed in the earth's atmosphere and oceans and the solar atmosphere, and to predict possible behavior of other planetary atmospheres and the earth's fluid core. These theories have not been possible to test on the ground due to the unavoidable and deleterious effects of the unidirectional gravitational field which destroys the crucial radial symmetry of many of the most pertinent experiments. The proposed experiments, and others in the same class of simulation, will be capable of achieving the proper degree of symmetry in 0-g and of producing very important information of both fundamental and practical impact.

TO BE CARRIED TO LEVEL _____

DEFINITION OF TECHNOLOGY REQUIREMENT		NO. 1
1. TECHNOLOGY REQUIREMENT(TITLE): <u>Experiments in a</u> PAGE 2 OF <u>3</u> <u>Large-Scale-Phenomenon Simulation Lab Module</u>		
7. TECHNOLOGY OPTIONS:		
<p>This module offers opportunities for other simulation experiments, such as terrella experiments to simulate solar particle streams interacting with the earth's magnetic field.</p>		
8. TECHNICAL PROBLEMS:		
<p>The state-of-the-art of precursor experiment hardware, which will be capable of measurements of limited scope on the ground, is progressing satisfactorily. No fundamental problems have been identified.</p>		
9. POTENTIAL ALTERNATIVES:		
<p>None known at present.</p>		
10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:		
<p>Ground experiments of increased sophistication will continue to provide some valuable data. However, with presently known technology, none can provide sufficiently precise simulation to answer the most critical questions.</p>		
<p style="text-align: right;">EXPECTED UNPERTURBED LEVEL <u> </u></p>		
11. RELATED TECHNOLOGY REQUIREMENTS:		

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 1

1. TECHNOLOGY REQUIREMENT (TITLE): Experiments in a PAGE 3 OF 3
Large-Scale-Phenomenon Simulation Lab Module

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Ground Research	I	I																	
2. Flight Expt. Defn.	I	I																	
3. Feasibility			I	I															
4. Instrumentation				I	I														
5.																			
APPLICATION																			
1. Design (Ph. C)					I	I													
2. Devl/Fab (Ph. D)						I	I												
3. Operations							I	I	I	I									
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																			TOTAL
NUMBER OF LAUNCHES							I	I	I	I									4

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.

5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 21. TECHNOLOGY REQUIREMENT (TITLE): Experiments in a PAGE 1 OF 3
Molecular Beam Lab Module

2. TECHNOLOGY CATEGORY: _____

3. OBJECTIVE/ADVANCEMENT REQUIRED: To perform a series of experiments
using properties of the space atmosphere.4. CURRENT STATE OF ART: Feasibility of module has been verified by
calculations Level 3, experiments and module modifications in early stage
of definition, Level 2. HAS BEEN CARRIED TO LEVEL

5. DESCRIPTION OF EXPERIMENTS

The Molecular Beam Lab can produce an environment of less than 10^{-18} torr of oxidants and less than 10^{-13} torr total pressure behind a molecular shield. High vacuum experiments such as thermodynamic characteristics of molecules in free expansion will be performed. An aperture at the shield vertex permits an energetic atmosphere beam to enter and interact in a controlled fashion with solids or other beams. Experiments with a beam include recombination of atomic species on surfaces, and reactions with surfaces or another beam. Data taking will be performed through mass spectra of beam products and surface analysis of reacted solids.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

- a.) Applied and fundamental experiments to be performed in a Molecular Beam Lab exploit the characteristics of the low density space atmosphere for unusual gas species and ultra high vacuum.
- b.) This module is part of SPDA sortie payload ST-07-S Neutral Beam Physics.
- c.) Initial measurements in space will be tests of design and procedures. Specifically, measurements will be made of ultimate pressure and partial pressure of identifiable species, beam characteristics and beam-energy reduction techniques.

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 2
1. TECHNOLOGY REQUIREMENT(TITLE): <u>Molecular Beam Lab</u> PAGE 2 OF 3	
7. TECHNOLOGY OPTIONS: This module offers opportunities for studying metal oxidation, catalysis, absorption, transport and distribution of oxygen in biological systems.	
8. TECHNICAL PROBLEMS: Potential problems: Shuttle contamination and shield outgasing, control of energy and flux of atmospheric beams.	
9. POTENTIAL ALTERNATIVES: 1. None now. 2. High intensity, pure atomic-oxygen beams of variable energy might be developed for terrestrial use by early 1980's.	
10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT: The shield for a Molecular Beam Lab is being developed for Space Processing. Mass spectrometers are being developed for OSS. Beam experiments and shield modifications are being studied in OAST Physics and Chemistry Experiments in Space Program. <div style="text-align: right;">EXPECTED UNPERTURBED LEVEL <u> </u></div>	
11. RELATED TECHNOLOGY REQUIREMENTS:	

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 2

1. TECHNOLOGY REQUIREMENT (TITLE): Molecular Beam Lab PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Experiment Defn.	I	I	I	I															
2. Feasibility	I	I																	
3.																			
4.																			
5. Instrumentation				I	I														
APPLICATION																			
1. Design (Ph. C)					I	I													
2. Devl/Fab (Ph. D)						I	I												
3. Operations								I	I	I	I	I	I	I	I	I	I	I	I
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																			TOTAL
NUMBER OF LAUNCHES								1	1	2	2								<6

14. REFERENCES:

1. Molecular Beam Lab, New Initiative for FY 77
2. Minutes for Physics and Chemistry Experiments Meeting Feb 1975

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.

5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 31. TECHNOLOGY REQUIREMENT (TITLE): Phase Transition and PAGE 1 OF 3
Critical Phenomena Experiments and Module2. TECHNOLOGY CATEGORY: Fluids Science3. OBJECTIVE/ADVANCEMENT REQUIRED: Observe phase transition and
make measurements of transport properties.4. CURRENT STATE OF ART: Normal gravity measurements of properties near
the critical point are severely complicated by large density gradients. Data
to augment theory requires reduced gravity exper- HAS BEEN CARRIED TO LEVEL 5. DESCRIPTION OF TECHNOLOGY iments.

In the critical region many thermodynamic and transport properties of fluids display an anomalous behavior. Very precise experimental measurements are required to quantify these anomalies. However, experiments under normal gravity conditions on earth can be influenced by large density inhomogeneities which occur near the critical point so that low gravity testing is necessary. Reduced gravity will also permit the observation of nucleation and phase transition without the disturbing influences of gravity driven sedimentation. Experiments that should be conducted include (1) visual observations (2) measurements of transport properties and (3) light scattering measurements to obtain statistical thermodynamics data. These experiments are all similar in environmental, instrumentation and data retrieval requirements so that a common module to provide this support should be constructed.

P/I. REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The critical region of fluids has been shown to possess a "universal" character. Thus, the thermodynamic and transport properties in the critical region of all pure fluids show common dependencies on the temperature and density difference from the critical point. This "universality" implies that experimental results from the study of the properties of one fluid will be immediately applicable to the description of the properties of other fluids.

The payload in which the experiments and module herein would be included is the fluid physics and heat transfer facility (ST-06-5) current feasibility and conceptual design studies will be completed for the first three experiments in 1975.

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 3

1. TECHNOLOGY REQUIREMENT(TITLE): Phase Transition and PAGE 2 OF 3
Critical Phenomena Experiments and Module

7. TECHNOLOGY OPTIONS:

The experiments are to photographically study phase transition phenomena, determine the constant volume specific heat near the critical point, and use light scattering measurements to determine the correlation length.

8. TECHNICAL PROBLEMS:

Feasibility studies are defining experimental instrumentation and procedural requirements for each investigation. No significant technical problems in this regard are anticipated.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 3

1. TECHNOLOGY REQUIREMENT (TITLE): Phase Transition and Critical Phenomena Experiments and Module PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Exp. Design		I	I																
2. Exp. Fabrication				I	I														
3. Module Design		I	I																
4. Module Fabrication				I	I														
5. Integration and Flight Check					I	I													
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

o flight

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																			TOTAL
NUMBER OF LAUNCHES																			

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.

5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 4

1. TECHNOLOGY REQUIREMENT (TITLE): Two Phase Heat PAGE 1 OF 3
Transfer Experiments and Module

2. TECHNOLOGY CATEGORY: Fluids Science

3. OBJECTIVE/ADVANCEMENT REQUIRED: To investigate various boiling
and bubble phenomena in a reduced gravity environment

4. CURRENT STATE OF ART: Drop tower and airplane studies on boiling have
shown, qualitatively, strong gravity effects. Longer reduced gravity test
times are required to reach a steady state condition. HAS BEEN CARRIED TO LEVEL

5. DESCRIPTION OF TECHNOLOGY

Numerous NASA inhouse and contracted studies have extensively investigated gravity effects on pool boiling, two phase flow and bubble dynamics. Qualitative information on all these processes have been obtained within the limitations of ground based facilities. The results are inconclusive in terms of their application to long term reduced gravity conditions. Work has been suspended until a long term facility is available. Space lab experiments are needed in the areas of (1) pool boiling - defining the standard boiling curve, (2) homogeneous bubble nucleation, growth and dynamics, and (3) two phase flow. Because of the similarity in requirements for these investigations, a test module providing common power, instrumentation, and data retrieval capabilities should be constructed.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The application of two phase heat transfer phenomena in such problem areas as propellant thermal conditioning and life support system operations in reduced gravity has provided the emphasis for interest in this work.

The payloads in which the experiments and module herein would be included is the fluid physics and heat transfer facility (ST-06-5).

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 4

1. TECHNOLOGY REQUIREMENT(TITLE): Two Phase Heat Transfer PAGE 2 OF 3
Experiments and Module

7. TECHNOLOGY OPTIONS:

The experiments are to be capable of studying numerous two phase heat transfer phenomena to include, saturated pool boiling, sub-cooled pool boiling, inception of boiling, burn out heat flux, bubble dynamics and growth, and two phase flow. Parameters to be varied include fluid, heat flux, flow rate, heater geometry, and heater surface characteristics.

8. TECHNICAL PROBLEMS:

None.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMEN

EXPECTED UNPERTURBED LEVEL ____

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT																	NO. 4	
1. TECHNOLOGY REQUIREMENT (TITLE): <u>Two Phase Heat Transfer Experiments and Module</u>																	PAGE 3 OF 3	
12. TECHNOLOGY REQUIREMENTS SCHEDULE:																		
CALENDAR YEAR																		
SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	
TECHNOLOGY																		
1. Exp. Design		I	I															
2. Exp. Fabrication				I	I													
3. Module Design		I	I	I														
4. Module Fabrication					I	I												
5. Integration and Flight Check						I	I											
								o flight										
APPLICATION																		
1. Design (Ph. C)																		
2. Devl/Fab (Ph. D)																		
3. Operations																		
4.																		
13. USAGE SCHEDULE:																		
TECHNOLOGY NEED DATE																		TOTAL
NUMBER OF LAUNCHES																		
14. REFERENCES:																		
1. Cochran, T. H.: Effects of Subcooling and Gravity Level on Boiling in the Discrete Bubble Region, NASA TN 1965 2. Lienhard, John: Extended Hydrodynamic Theory of the Peak and Minimum Pool Boiling Heat Fluxes. NASA CR-2270, 1973																		
15. LEVEL OF STATE OF ART																		
1. BASIC PHENOMENA OBSERVED AND REPORTED. 2. THEORY FORMULATED TO DESCRIBE PHENOMENA. 3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL. 4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.									5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY. 6. MODEL TESTED IN AIRCRAFT ENVIRONMENT. 7. MODEL TESTED IN SPACE ENVIRONMENT. 8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL. 9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL. 10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.									

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 51. TECHNOLOGY REQUIREMENT (TITLE): Fluid Physics Experiments PAGE 1 OF 32. TECHNOLOGY CATEGORY: Fluids Science3. OBJECTIVE/ADVANCEMENT REQUIRED: To observe the behavior of basic fluid physics phenomena in the absence of natural convection and body forces.4. CURRENT STATE OF ART: An understanding of numerous complex fluid physics phenomena is complicated by the interaction of natural convection and body force effects with other transport processes. HAS BEEN CARRIED TO LEVEL

5. DESCRIPTION OF TECHNOLOGY

An understanding of numerous fluid physics phenomena on earth frequently is complicated by the competing influences of more than one driving influence. In addition, gravitational effects on earth often mask or dominate effects which can control processes in space. The interrelation between natural convection with such nongravity driving forces as surface tension, thermal-volume expansions and electric fields are examples. Body forces can play a similar role with these driving influences. Space experimentation will permit the isolation of these nongravity convection processes permitting a test of analytical models. Also, the elimination of body force effects will allow experiments to be conducted that would otherwise be impossible on earth. Experiments are to be conducted in the area of (1) convection phenomena, (2) hydrodynamic instabilities and (3) multiphase phenomena (foams and aerosols).

P/I. REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

These studies will yield information that will lead to a better understanding of physical phenomena on earth as well as in space. For example, this work will lead to a better understanding of processes concerned with space processing, liquification of natural gas, flame spreading on liquids, propellant behavior in space, numerous industrial processes involving liquid jets, and fighting fire with foams.

The payload in which the experiments would be included in is the fluid physics and heat transfer facility (ST-06-5).

Current feasibility and conceptual design studies will be completed in CY 78.

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 5
1. TECHNOLOGY REQUIREMENT(TITLE): <u>Fluid Physics Experiments</u>	PAGE 2 OF 3
<p>7. TECHNOLOGY OPTIONS:</p> <p>The experiments are to be capable of studying numerous fluid physics phenomena including surface tension driven flows, low gravity convection, phase change convection, liquid jet instabilities, gas jet instabilities, form stability and aerosol dynamics. Parameters to be varied include fluids, environmental conditions, and heat transfer rates.</p>	
<p>8. TECHNICAL PROBLEMS:</p> <p>Feasibility studies are defining instrumentation and procedural requirements for each experimental area. No significant technical problems in this regard are anticipated.</p>	
<p>9. POTENTIAL ALTERNATIVES:</p>	
<p>10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:</p> <p>Current feasibility and design studies for the experiments are being carried out under the physics and chemistry experiments program under RTOP 750-01-51.</p> <p style="text-align: right;">EXPECTED UNPERTURBED LEVEL <u> </u></p>	
<p>11. RELATED TECHNOLOGY REQUIREMENTS:</p>	

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 5

1. TECHNOLOGY REQUIREMENT (TITLE): Fluid Physics Experiments PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1 Experiment Design				I	I														
2 Experiment Fabrication					I	I													
3 Flight Check and Integration							I												
4 Flight							0												
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																			TOTAL
NUMBER OF LAUNCHES																			

14. REFERENCES:

1. Dodge, Franklin; Fluid Physics, Thermodynamics, and Heat Transfer Experiments in Space. NASA CR-134742, 1975

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.

4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.

5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.

6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.

7. MODEL TESTED IN SPACE ENVIRONMENT.

8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.

9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.

10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 61. TECHNOLOGY REQUIREMENT (TITLE): Combustion PAGE 1 OF 3
Experiments and Module2. TECHNOLOGY CATEGORY: Combustion Science3. OBJECTIVE/ADVANCEMENT REQUIRED: To observe and make critical
measurements of various combustion processes in reduced gravity4. CURRENT STATE OF ART: Theoretical modeling of processes and basic
phenomenological understanding is limited because of access to only normal
gravity data. HAS BEEN CARRIED TO LEVEL

5. DESCRIPTION OF TECHNOLOGY

Analytical predictions of combustion phenomena neglect gravity because its inclusion severely complicates problem solving. However, experimental data obtained on earth clearly show strong gravity effects. The availability of zero gravity data will permit a careful assessment of existing "zero g" analyses as well as providing a basis from which to formulate rational gravity dependent solutions. Experiments should be conducted on the combustion of (1) droplets, (2) particles, (3) large solid surfaces, (4) large liquid surfaces, and (5) gases. These experiments are all similar in environmental instrumentation, and data retrieval requirements so that a common module capable of providing this support should be constructed.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

These studies are substantially oriented toward the generation of information that will lead to a better understanding of physical phenomena on earth. The value of this work is clear when one considers its application to such problems as more efficient cleaner power generation and home heating units, fire safety in terms of forest fires, mine explosions, and industrial accidents.

The payload in which the experiments and module herein would be included is the fluid physics and heat transfer facility (ST - 06 - 5).

Current feasibility and conceptual design studies will be completed for the first five experiments in CY 78.

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 6

1. TECHNOLOGY REQUIREMENT(TITLE): Combustion Experiments PAGE 2 OF 3
and Module

7. TECHNOLOGY OPTIONS:

The experiments are to be capable of studying numerous combustion processes, to include ignition, transient burning, steady state burning, and extinction. Parameters to be varied include environmental pressure, environmental constituents, environmental temperature, and fuel geometry.

8. TECHNICAL PROBLEMS:

Feasibility studies are defining experimental instrumentation and procedural requirements for each investigation. No significant technical problems in this regard are anticipated.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Current feasibility and design studies for the experiments are being carried out under the Physics and Chemistry experiments program under RTOP 750-01-51.

EXPECTED UNPERTURBED LEVEL

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT																NO. 6			
1. TECHNOLOGY REQUIREMENT (TITLE): <u>Combustion Experiments</u>																PAGE 3 OF <u>3</u>			
and Module																			
12. TECHNOLOGY REQUIREMENTS SCHEDULE:																			
CALENDAR YEAR																			
SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Exp. Design				I	I														
2. Exp. Fabrication					I	I													
3. Module Design			I	I															
4. Module Fabrication				I	I														
5. Integration and flight check					I	I													
								o	flight										
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			
13. USAGE SCHEDULE:																			
TECHNOLOGY NEED DATE																	TOTAL		
NUMBER OF LAUNCHES																			
14. REFERENCES:																			
<p>1. Study of Combustion Experiment in Space, CR - 134744</p>																			
15. LEVEL OF STATE OF ART																			
<p>1. BASIC PHENOMENA OBSERVED AND REPORTED.</p> <p>2. THEORY FORMULATED TO DESCRIBE PHENOMENA.</p> <p>3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.</p> <p>4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.</p>									<p>5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.</p> <p>6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.</p> <p>7. MODEL TESTED IN SPACE ENVIRONMENT.</p> <p>8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.</p> <p>9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.</p> <p>10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.</p>										

APPENDIX 3. FUTURE PAYLOAD TECHNOLOGY

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**FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT**

NO. 1
PAGE 1

1. REF. NO. _____	PREP DATE _____	REV DATE _____	LTR _____
CATEGORY _____			
2. TITLE <u>Ultra-High Q Gravity Wave Detectors</u>			
3. TECHNOLOGY ADVANCEMENT REQUIRED	LEVEL OF STATE OF ART		
1) High Q sapphire rod.	CURRENT	UNPERTURBED	REQUIRED
2) Superconducting-magnetic suspension.	2	3	7
3) Sensor mechanism of sufficient sensitivity and low noise.			
4) Space compatible cryogenic system delivering temperature of .01°K.			
4. SCHEDULE REQUIREMENTS			
		FIRST PAYLOAD FLIGHT DATE <u>Mid 1980's</u>	
PAYLOAD DEVELOPMENT LEAD TIME <u>8</u> YEARS.		TECHNOLOGY NEED DATE <u>1980</u>	
5. BENEFIT OF ADVANCEMENT			
		NUMBER OF PAYLOADS <u>2 minimum</u>	
TECHNICAL BENEFITS <u>Advance state-of-art of detection of gravity waves.</u>			
<u>Increase sensitivity by 10¹⁸ or more. Verify prediction of Einstein's</u>			
<u>General Theory of Relativity.</u>			
POTENTIAL COST BENEFITS _____			
		ESTIMATED COST SAVINGS \$ _____	
6. RISK IN TECHNOLOGY ADVANCEMENT			
TECHNICAL PROBLEMS <u>1) Demonstrate Q of 10¹⁸ of single crystal sapphire rod</u>			
<u>of large size operated at .01°K, 2) Demonstrate superconducting-magnetic</u>			
<u>support system for rod, 3) Demonstrate vibration detection schemes of suffi-</u>			
<u>cient sensitivity and low noise, 4) Demonstrate capability to maintain rod at</u>			
<u>.01°K in space for long periods of time.</u>			
REQUIRED SUPPORTING TECHNOLOGIES _____			
7. REFERENCE DOCUMENTS/COMMENTS _____			

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION

TEST ARTICLE: Entire SystemTEST DESCRIPTION: ALT (max/min) Any / Orbital km, INCL. Any deg, TIME 24 hrBENEFIT OF SPACE TEST: Suspension system critical. Could not operate in 1-g.
Also test of Q of sapphire rod as suspended.EQUIPMENT: WEIGHT 1,000 kg, SIZE 1 X 1 X 1 m, POWER 1 kWPOINTING 3 periods, 10, 10 min STABILITY _____ DATA _____ORIENTATION Any CREW NO. 1 OPERATIONS/DURATION 3 / 1/2 hr

SPECIAL GROUND FACILITIES: _____ ea.

EXISTING: YES ☐ NO ☐TEST CONFIDENCE 75%

9. GROUND TEST OPTION

TEST ARTICLE: Lab research, zero-g aircraft.TEST DESCRIPTION/REQUIREMENTS: Each element of system as described above.

SPECIAL GROUND FACILITIES: _____

EXISTING: YES ☐ NO ☐GROUND TEST LIMITATIONS: See under space test.TEST CONFIDENCE 50%

10. SCHEDULE & COST

10. SCHEDULE & COST		SPACE TEST OPTION							GROUND TEST OPTION								
TASK	CY	75	77	79	81	83	85	COST (\$)	75	77	79	81	83	85	COST (\$)		
1. ANALYSIS		xxx						100k	xx	xxx	xx				100k		
2. DESIGN			xxx					400k		xx	xxx				500k		
3. MFG & C/O			x	xxx				400k			xxx	xx			500k		
4. TEST & EVAL				v				100k				xxx	xx		900k		
TECH NEED DATE																	
		GRAND TOTAL							\$1M	GRAND TOTAL							\$2M

11. VALUE OF SPACE TEST \$ _____ (SUM OF PROGRAM COSTS \$ _____)

12. DOMINANT RISK/TECH PROBLEM

Q of sapphire rod.

COST IMPACT _____

PROBABILITY _____

COST RISK \$ _____

**FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT**

NO. 2
PAGE 1

1. REF. NO. _____	PREP DATE _____	REV DATE _____	LTR _____
CATEGORY _____			
2. TITLE <u>Superfluid Helium Dewar Control for Cryogenic Cooling Test in Zero-G</u>			
3. TECHNOLOGY ADVANCEMENT REQUIRED <u>Test Properties of Superfluid Helium in Zero-Gravity:</u>	LEVEL OF STATE OF ART		
	CURRENT <u>6</u>	UNPERTURBED <u>6</u>	REQUIRED <u>7</u>
<u>1) Liquid Distribution and Dynamics</u> <u>2) Control of Undesirable Bulk Oscillations</u> <u>3) Efficient Liquid-Vapor Separation and Venting</u> <u>4) Control of Undesired Thermo-Mechanical Oscillations</u> <u>5) Heat Transfer in Bulk and Thin Films</u>			
<u>Test Dewar Efficiency</u>			
4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE <u>1979 (IRAS)</u>			
PAYLOAD DEVELOPMENT LEAD TIME <u>2</u> YEARS. TECHNOLOGY NEED DATE <u>1977</u>			
5. BENEFIT OF ADVANCEMENT		NUMBER OF PAYLOADS <u>>10</u>	
TECHNICAL BENEFITS <u>I. Conduct following NASA missions: 1) Infrared survey Satellite, 2) Large space telescope IR capability, 3) Shuttle IR telescope facility, 4) Stanford relativity test. II. Support superconducting devices: 1) Magnets, 2) Detectors, 3) Computers. III. Conduct basic helium experiments: 1) Lambda point, 2) Critical point, 3) He₃/He₄ consolute point, 4) Quantum fluid drop dynamics.</u> POTENTIAL COST BENEFITS <u>All missions impossible without liquid helium cooling.</u>			
ESTIMATED COST SAVINGS \$ _____			
6. RISK IN TECHNOLOGY ADVANCEMENT			
TECHNICAL PROBLEMS <u>1) Highly efficient cryogenic storage systems in Zero-G. 2) Highly efficient heat transfer mechanisms in Zero-G.</u>			
REQUIRED SUPPORTING TECHNOLOGIES <u>Highly efficient insulation techniques.</u>			
7. REFERENCE DOCUMENTS/COMMENTS <u>RTOP attached.</u>			

TITLE Superfluid Helium Dewar Control for Cryogenic Cooling
Test in Zero-G

NO. 2

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Instrumented test dewar;

1) Rocket 2) Orbital spacecraft

TEST DESCRIPTION: ALT. (max/min) 1) 320 km 10 min.
2) Orbital/ km, INCL. deg, TIME 7 days hr
Test zero-g dynamics, damping methods, oscillation control heat transfer.

BENEFIT OF SPACE TEST: Demonstration of desired life and thermal characteristics.
Demonstration of control of undesired oscillations.

EQUIPMENT: WEIGHT 100 kg, SIZE 1 X 1 X 1 m, POWER 1/2 kW
POINTING 1 degree STABILITY 0.1 degree DATA
ORIENTATION any CREW: NO. 1 OPERATIONS/DURATION 1 / hr.

SPECIAL GROUND FACILITIES: Liquid helium fill capacity

EXISTING: YES ☐ NO ☒

TEST CONFIDENCE 95%

9. GROUND TEST OPTION TEST ARTICLE: Lab research; zero-g aircraft

TEST DESCRIPTION/REQUIREMENTS: Develop instrumentation. Conduct limited time
zero-g tests to verify function.

SPECIAL GROUND FACILITIES: KC-135 aircraft

EXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: Short time, poor control of acceleration environment,
possibility of unexpected phenomena

TEST CONFIDENCE 70%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST (\$)	GROUND TEST OPTION						COST (\$)
		75	76	77	78	79	80								
1. ANALYSIS		┌───┐						100k	┌───┐						50k
2. DESIGN			┌───┐					500k	┌───┐						150k
3. MFG & C/O			┌───┐					900k	┌───┐						150k
4. TEST & EVAL					▽			300k	┌───┐						150k
TECH NEED DATE															
GRAND TOTAL								1,800k	GRAND TOTAL						500k

11. VALUE OF SPACE TEST \$ _____ (SUM OF PROGRAM COSTS \$ _____)

12. DOMINANT RISK/TECH PROBLEM

Undesired oscillations causing heat loss

COST IMPACT

500k

PROBABILITY

25%

Unexpected phenomena

?

25%

COST RISK \$ _____

NO. 3
PAGE 1

FT (TDR-1) 7/75

TITLE Low Temperature ModuleNO. 3PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION

TEST ARTICLE: Low Temperature Module

TEST DESCRIPTION: ALT. (max/min) Orbital / km, INCL. deg, TIME hr
Conduct ultra-precise measurements of physical properties of superfluid
helium.

BENEFIT OF SPACE TEST: Long duration of zero-g time.
Absence of spatially varying gravitational potential.

EQUIPMENT: WEIGHT 500 kg, SIZE 2 X 2 X 2 m, POWER 1 kWPOINTING STABILITY 10⁻⁶g DATA ORIENTATION CREW: NO. 1 OPERATIONS/DURATION /

SPECIAL GROUND FACILITIES: Pressure control equipment. Liquid helium fill
capability.

EXISTING: YES ☒ NO ☐TEST CONFIDENCE .7

9. GROUND TEST OPTION

TEST ARTICLE: Low temperature module

TEST DESCRIPTION/REQUIREMENTS: Laboratory and KC-135 aircraft flight as
preliminary to orbital flight.

SPECIAL GROUND FACILITIES: KC-135 aircraftEXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: Poor G level, short duration, gravitational potential
varying in sample imply cannot perform meaningful experiments.

TEST CONFIDENCE 0

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST (\$)	GROUND TEST OPTION						COST (\$)
		78	79	80	81	82	83								
1. ANALYSIS		.5	.5					1.0M	No meaningful results.						
2. DESIGN			.7	.8	1.0			2.5M							
3. MFG & C/O					1.0	1.0		2.0M							
4. TEST & EVAL						1.5	1.5	3.0M							
TECH NEED DATE															
GRAND TOTAL								8.5M	GRAND TOTAL						

11. VALUE OF SPACE TEST \$ (SUM OF PROGRAM COSTS \$ 10M --)

12. DOMINANT RISK/TECH PROBLEM

COST IMPACT

PROBABILITY

1) Vortex line visualization.2) Ultra-precise temperature control.COST RISK \$

**FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT**

NO. 4
PAGE 1

1.	REF. NO. _____	PREP DATE _____	REV DATE _____	LTR _____									
	CATEGORY _____												
2.	TITLE <u>Drop Dynamics Module</u>												
3.	TECHNOLOGY ADVANCEMENT REQUIRED Provide capability to suspend one-inch drop of any liquid free from contact with walls in zero gravity against disturbance of $10^{-3}g$. Provide capability to rotate, oscillate, excite, fission and fuse drop. 	<table border="1" style="width:100%; border-collapse: collapse;"> <tr> <th align="center" colspan="3">LEVEL OF STATE OF ART</th></tr> <tr> <th align="center">CURRENT</th><th align="center">UNPERTURBED</th><th align="center">REQUIRED</th></tr> <tr> <td align="center">6</td><td align="center">6</td><td align="center">7</td></tr> </table>			LEVEL OF STATE OF ART			CURRENT	UNPERTURBED	REQUIRED	6	6	7
LEVEL OF STATE OF ART													
CURRENT	UNPERTURBED	REQUIRED											
6	6	7											
4.	SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE <u>1980</u> PAYLOAD DEVELOPMENT LEAD TIME <u>5</u> YEARS. TECHNOLOGY NEED DATE <u>1978</u>												
5.	BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS <u>16</u> TECHNICAL BENEFITS <u>(1) Position sample regardless of the electrical properties, (2) Rotate and oscillate the sample without physical contact, (3) Transfer and shape sample remotely. Conduct scientific experiments on dynamics of free and rotating drops.</u> POTENTIAL COST BENEFITS <u>Module capable of accommodating many experiments will result in a 50% cost reduction in the total program.</u> <div style="text-align: right;">ESTIMATED COST SAVINGS \$ <u>10M</u></div>												
6.	RISK IN TECHNOLOGY ADVANCEMENT TECHNICAL PROBLEMS <u>1) Drop suspension without distortion or excitation,</u> <u>2) Dynamic stability of drop.</u> REQUIRED SUPPORTING TECHNOLOGIES _____ 												
7.	REFERENCE DOCUMENTS/COMMENTS <u>JPL Drop Dynamics Module Project Plan</u> <u>(to be published)</u> 												

TITLE Drop Dynamics ModuleNO. 4PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION

TEST ARTICLE: Acoustic positioning chamber

TEST DESCRIPTION: ALT. (max/min) 500 / 250 km, INCL. Any deg, TIME 10 hr
Demonstrate all capabilities of flight system: suspension, rotation,
oscillation, fission, fusion, injection of many test samples.

BENEFIT OF SPACE TEST: Long duration, low gravity.EQUIPMENT: WEIGHT 200 kg, SIZE 1 X 1 X 1 m, POWER .2 kWPOINTING _____ STABILITY 10⁻⁶g DATA _____ORIENTATION _____ CREW: NO. 1 OPERATIONS/DURATION 2 / 1/2 hr

SPECIAL GROUND FACILITIES: _____

EXISTING: YES ☐ NO ☐TEST CONFIDENCE .9

9. GROUND TEST OPTION

TEST ARTICLE: Acoustic positioning chamberTEST DESCRIPTION/REQUIREMENTS: Laboratory and KC-135 aircraft flightSPECIAL GROUND FACILITIES: KC-135 aircraftEXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: Residual G >> 10⁻⁴g (min. required for experiment)
duration 20 sec << τ (min. time required for equilibrium).

TEST CONFIDENCE .5

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST (\$)	GROUND TEST OPTION						COST (\$)
		76	77	78	79	80	81		76	77	78	79	80	81	
1. ANALYSIS		<u>.2</u>							<u>.2</u>						<u>.2</u>
2. DESIGN			<u>.5</u>	<u>.7</u>						<u>.2</u>	<u>.2</u>				<u>.4</u>
3. MFG & C/O				<u>.3</u>	<u>.5</u>						<u>.2</u>	<u>.2</u>			<u>.4</u>
4. TEST & EVAL						<u>.2</u>							<u>.2</u>		<u>.2</u>
TECH NEED DATE															
GRAND TOTAL								<u>2.4M</u>	GRAND TOTAL						<u>1.2M</u>

11. VALUE OF SPACE TEST \$ 50M(SUM OF PROGRAM COSTS \$ 100M)

12. DOMINANT RISK/TECH PROBLEM

Dynamic stability of drop

COST IMPACT

250k

PROBABILITY

25%

COST RISK \$ _____

II. BASIC RESEARCH MISSION-ORIENTED NEEDS OVERVIEW

In order to fulfill its second important function at the workshop of providing a basic research view of NASA's programs, the Basic Research Working Group compiled research requirements from a variety of sources. These were discussed at length and synthesized into the technical summaries and recommendations which form the body of this section of the report.

The first type of research input consisted of specific requirements for basic research which were solicited by the BRWG from the other technology working groups. These inputs fall into essentially four categories: research in areas not covered by any of the working groups, but perceived by the submitting group to impact their programs; research which covers more than one discipline; research of a longer range than covered by the group; and a working group's entire research plan, which will therefore appear in some form in that group's report. These submissions were individually considered and compiled into the condensed, annotated list which is given in Section II A.

The second type of research input resulted from a careful search of the needs of the mission oriented users, namely the non-OAST program offices. The details of this process and a cross referenced list of identified needs are given in Section II B.

The third form of input to **this function** was the scientific and technological background and knowledge which the

Working Group members themselves provided. It permitted us to perform an integration process which resulted in the two parts of Section II C and which, as specific recommendations to OAST management, we feel comprises the most important output of the Basic Research Working Group.

In the first part of II C we give the eleven basic research needs most frequently identified by the users together with lists of the reference missions identified in the user source documents. From that list we have chosen five which we feel offer NASA the greatest potential for intermediate and long range mission benefit and which warrant particular research attention. These five are:

- 1) Quantum Electronics, to include lasers and optoelectronic devices,
- 2) Cryogenic Systems Technology, to include normal cryogens and superfluid helium,
- 3) Superconducting Quantum Devices and Detectors,
- 4) Photo Induced Reactions,
- 5) Bioengineering (non-OAST).

The justification for our conclusions are documented in a separate subsection for each of the five subjects in Section II C. We recognize the OMSF responsibility for Bioengineering, but felt, nevertheless, that it deserved a place in our list.

The second part of Section II C presents and discusses a recommendation which we, as scientists at the research working level, each within a different NASA Center, have developed from our past experience and within the forum provided by this Work-

shop. It deals with our concern for maintaining an affirmative dialogue between the Center research staffs and the users who develop the mission needs. For emphasis we summarize this recommendation here:

User offices are conducting missions which could receive particular benefit from existing OAST research and technology programs. The basic research working group strongly recommends that a mechanism be evolved to insure timely synthesis of your user needs into OAST programs. This should be implemented at both the management and working levels.

A. DISCIPLINE WORKING GROUP NEEDS

The Basic Research Working Group solicited and received a total of 52 Requirement for Basic Research forms from the other technology Working Groups. Five of these were felt by the BRWG to be inappropriate or were withdrawn. For example, two involved experiments already specifically being planned under the OA Space Processing Applications Program. In several instances closely related requirements, e.g., solid state diffusion, were combined. The remaining requirements were then condensed into concise summaries, grouped into general areas where commonality exists, and listed. Some of the requirements call for an experiment in space, either exclusively or as part of a broader study involving ground research; these are identified by an asterisk (*). Many of them are not new to OAST, but serve to reemphasize the value of the particular area. Certainly the list is not all-inclusive--the limits imposed by the knowledge and interest of the total workshop complement and by time, must have led to the omission of useful studies.

MATERIALS

1. Microcircuit Reliability--Failure Physics - NASA mission needs demand reliability, especially in microcircuits, far in excess of those of the DOD or industry. More emphasis needs to be given to the physics of failure mechanisms in semiconductors. Specifically, intensive studies on the behavior of impurities in oxides, tolerance limits on manufacture process-introduced contaminants, long-term physiochemical effects, and development of techniques to accelerate long-life tests should be begun.

2. Semiconductor Research for Solar Cells - Improved understanding is needed to develop better solar cells. For example, the open circuit voltage (and efficiency) of silicon cells is 10% lower than expected. Better growth and characterization technique for GaAIAs type (III-V) solar cells materials are required for implementation of graded band gap concepts. Reduction or elimination of residual and accidentally introduced centers, which reduce the efficiency through recombination in the bulk, in the junction and at the surface, will be important for continued device improvement.

3. Basic Studies of Diffusion and Electromigration in Metals and Alloys - Theoretical and experimental research is required to develop and verify a quantitative theory of diffusion in alloys in order to permit accurate diffusion predictions to provide diffusion data for alloy systems of practical interest at their operating temperatures, and to establish a basic understanding of the electromigration process in metals and alloys in order to guide the alleviation of the phenomenon in microcircuitry. Well controlled diffusion experiments should be conducted to provide diffusion constants and activation energies in a variety of alloy systems including data and a search for possible new mechanisms at high temperatures; calculations are required of such subjects as energies of formation, number of vacancies, relation of bonding energy and activation energy for diffusion, definition of elementary jump processes, and impurity diffusion. Electromigration, though in hand for present microcircuitry, will reappear as a problem

as further circuit size reductions occur.

4. Thermionic Converters for Nuclear Electric Power -

Research is proposed on out of-core thermionic emitters for nuclear electric power to achieve a conversion efficiency in excess of 30%. Fundamental research will be required on (1) high density, high purity single crystals, (2) thermionic properties of bare, cesiated and oxidized electrodes, and (3) surface and bulk properties of electrodes.

5. Research on Isotope Power Systems for NASA Missions -

Research is needed to develop a fundamental theory to characterize the operation of thermoelectric conversion materials and devices employed in isotope power supplies. Such work will permit NASA to develop realistic performance specifications to guide ERDA. In addition, work is required aimed at developing low cost, less hazardous simulators which duplicate flight item sources but will permit easier, lower interference testing of instruments prior to launch.

6. Basic Studies of New Concepts for Solar Cells - Research is required to examine relevant physical phenomena in order to develop more efficient, lower cost methods for conversion of solar energy to electricity. Studies should include such subjects as electron-phonon interactions in semiconductors, dye sensitized optical absorption to increase the usable spectral band, surface atomic states, and the search for new materials, such as gallium arsenide.

7. Basic Studies of Fiber-Matrix Composites - Fundamental understanding is required of the structure and behavior of

fiber-matrix composites at the atomic level in order to provide guidance for their development and application, and for the synthesis of new materials. Studies should be made in such areas as the relation between fiber morphology and mechanical behavior of the fibers; physics and chemistry of fiber-matrix interfaces; chemistry of polymers for composite applications; internal friction, elasticity and internal stress distributions in fibers; thermal fatigue in composite structures; and others. The state of the art is now at a point where the development of basic understanding can provide the most profitable approach to improved materials.

8. Studies of Creep and Fracture Mechanisms in Composites -

Research is required to develop a fundamental understanding of the mechanisms of deformation and fracture of composite materials in order to guide the development of improved structural materials. Studies should include such areas as fiber-matrix interactions during straining, load transfer modes, surface flow effects on cracks, and the role of grown-in stress distributions.

9. Catalysts for Low Temperature Fuel Cells - New catalysts are required for low temperature fuel cells which will be inexpensive and have long life. The new catalysts must be relatively inexpensive compared to present platinum and gold catalysts and more resistant to poisoning. These catalysts must be effective below 150°C.

10. Basic Studies in Catalysis - Theoretical and experimental research at a substantial level is required to obtain a funda-

mental understanding of the mechanisms of catalysis in order to guide the development of fuel cells, propellant catalysts and life support gas conditioning. Recent theoretical research on surface interatomic potential perturbation by adsorbing atoms and on the possibility of duplicating catalytic properties in certain compounds should be exploited, expanded and tested. Also, new methods of preparation of catalyst metals of high purity and fine subdivision, including possibly space processing techniques, should be studied.

11. Research on Organic Superconductors - Theoretical and experimental research should be conducted to develop concepts for organic superconductors which, if possible to synthesize, are hypothesized to have significantly higher superconducting transition temperatures. Further theoretical solid state studies, and experimental work in synthetic organic chemistry are required.

12. Superconducting Metals Research - The potential impact of modest increases (several degrees Kelvin) in the transition temperatures of superconducting metals, in permitting practical device operation in boiling hydrogen, indicates strongly that NASA should maintain an active interest in and support of research on higher transition temperature superconducting alloys and compounds.

13. Variable Coatings for Spacecraft Temperature Control - For spacecraft thermal control, materials are needed which exhibit large reproducible changes in solar transparency/reflectance or thermal emittance with temperature. The temp-

erature at which the solar absorptance or thermal emittance changes should be selectable over a wide temperature range. In addition, the materials must be radiation tolerant and stable against thermal and ultraviolet degradation.

14. Basic Studies in Electrochemistry - Research should be conducted at an increased level to gain fundamental understanding in the areas of electrochemistry and physical chemistry leading to the development of more efficient, reliable batteries. Studies should include such areas as polymeric structures for battery separators, electrochemistry of high concentration electrolyte systems, electrode reactions, and electrodeposition morphology.

15. Basic Studies of the Mechanism of Hydrogen Embrittlement - Theoretical and experimental research at an increased level should be conducted to obtain fundamental understanding of the solid state and surface chemical processes involved in the many undesirable hydrogen embrittlement phenomena. Study areas should include hydrogen atom interactions, with dislocations and crack tips, hydrogen dissociation on surfaces, and mechanisms of delayed fracture, and others. Multidisciplinary approaches are essential due to the wide variety of situations in which the phenomenon presents itself.

16. Studies of the Relation Between Molecular Structure and Mechanical Behavior of Polymers - Research is required at an augmented level to generate fundamental understanding of the relationship between the detailed molecular structure of a polymer molecule and the bulk mechanical behavior of the poly-

mer. This will permit design of polymers for specific mechanical applications, such as structural materials and the matrix component of composites.

17. Measurement of Vapor Pressures of Corrosive Materials -

Research is required to provide thermodynamic information for non-metallic materials whose corrosiveness requires that levitation be employed to prevent container contamination.

Studies should include Langmuir vaporization rate measurements coupled with mass spectrometric identification of vaporized species from specimens which are heated in high vacuum. This research has application to the hot corrosion problem experienced in aircraft turbine buckets, marine turbines and terrestrial power stations.

SURFACE CONTAMINATION

18. Basic Studies of Gas-Surface Reactions - Research is required at an increased level to gain a fundamental understanding of the interaction of gas molecules with solid surfaces. The interaction of material surfaces with the environment is of great importance in many areas from planetary entry to corrosion of terrestrial devices. Studies in chemisorption should include such parameters as the nature of the absorbed layer, surface distribution, cross sections and rates of deposition.

19. Spacecraft Outgassing Studies - Research is required on three aspects of the problem of outgassing of shuttle surfaces in space: (a) studies of the interaction of residual atmospheric constituents with shuttle surfaces, paints, etc., to

determine energy deposition distributions and rates, and thus to evaluate the outgassing problem as a function of material; (b) sensitive residual gas analyzer experiments to obtain differential outgassing data to permit the modeling of outgassing mechanisms. (This will impact the choice of materials to prevent contamination of ultraviolet experiments); and (c) Skylab observations indicated anomalous contaminant depositions during an anomalous oxidizer release. Since the shuttle vernier engine employs such oxidizers which can impinge on thermal control surfaces, quantitative study of induced outgassing and possible degradation is required.

20. Migration of Contaminants Along Surfaces - Studies are required of the migration of contaminants along surfaces between instruments operating at different temperatures. This problem exists, for example, for multiple devices in a common enclosure, even at relatively low temperatures, and can lead to serious serious sensor degradation.

21. Extravehicular Contamination Restrictions and Effect on Optical Sensors - Extravehicular activity (EVA), spacecraft leakage, dumps and outgassing contaminate the space atmosphere near the Shuttle. These contaminants may harm the optical sensors and systems of Shuttle experiments. To avoid loss of data and undue restrictions on EVA and other spacecraft operations, the detrimental effects of Shuttle contamination must be made quantitative. Consideration should be given to the following:

1. Determination of maximum acceptable contamination on sensors and optical systems by various vapors and gases.
2. Mechanisms and rates of contamination.
3. Sensor protection or configuration change.
4. Modification of vent location or time frequency of dumps.
5. Decay rates of contaminants in Shuttle environment with time.
6. Synergistic effects of mixed contaminants.

FLUIDS

22. Metal/Gas Battery Fluid Management - During the operation of high-energy-density metal/gas batteries, bubbles are generated at the negative electrode and, under normal gravity conditions, move through the electrolyte to a gas reservoir. Under reduced gravity conditions, buoyancy is no longer available as a driving mechanism for bubble removal. Bubble coverage on the electrode would result in decreased charge acceptance during charging. A technique for properly managing the bubbles is therefore required.

23. Reduced Gravity Fluid Management - The design of devices associated with the acquisition, thermal control and transfer of fluids in space will require advance in the state-of-the-art of reduced gravity fluid physics. Particular problems of concern include interfacial disturbances, liquid jet - solid interactions, and bubble dynamics. These phenomena are an integral part of processes such as reorientation of propellants prior to a restart, disturbances caused by deployment or docking of spacecraft, chill down of a propellant tank prior to

filling in space, and the operation of a thermodynamic vent system.

24. He^{II} Behavior - The purpose of this proposed research is the observation of He^{II} properties in weightlessness. Numerous requirements for the use of He^{II} in cooling scientific experiments have been identified for early shuttle missions. A better understanding of the unique behavior, including heat transfer and fluid dynamic phenomena, is required in order to adequately respond to these requirements. The work proposed is to consist of theoretical studies, laboratory experiments, and space demonstrations.

25. High Temperature Plasma Core Fission Reactor Fluid Mechanics Experiments in Low G - The open cycle plasma core nuclear rocket requires essentially complete separation of the flow of the propellant from the fissioning plasma. Low density propellant is expelled at high velocity, while the high density nuclear fuel is retained in the core. Laboratory experiments simulating these fluid flow requirements are currently showing significant influence by gravity. A need therefore exists for the experimental research study of fluid mechanics in a low- or zero-g environment.

LIFE SUPPORT

26. Air Quality Standards - In the past, manned spacecraft have had relatively clean cabin environments due to control of cabin structural materials. With the advent of a 14.7 psia cabin pressure, materials control will be relaxed and new potential contaminants may result. Hence, more comprehensive

standards will have to be identified to allow design specification and performance testing of contamination control systems.

27. Water Quality Standards - Spacecraft water provision systems, for consumption and cleansing, must operate within allowable chemical and biological limits. The present limited set of water standards must be expanded and techniques must be developed for testing and treating processed water.

28. Personal Hygiene Requirements for Long Missions - There will be a need during long duration missions to perform whole body bathing and clothes laundering. Research must be performed to: (1) establish cleanliness requirements for such missions, (2) identify technology advancements necessary to improve weight, volume, and power requirements of washer/driers, and (3) formulate a cleansing agent that is completely compatible with man, water processors, and personal hygiene equipment.

INSTRUMENT DEVELOPMENT

29. Hybrid U.V. --- CCD Materials - An array of solid state U.V. sensors on a solid state CCD array is needed that can both detect ultraviolet light and process the output. Materials research is required to develop a compatible layer of U.V. detector on a silicon CCD array. This integrated array is intended for detecting U.V. celestial sources and planetary atmospheres.

30. Room Temperature Infrared Detector - There is a need to understand the mechanism of the IR Photo-Electron relationship

in room temperature IR materials, e.g., pyroelectric materials or mixed inorganic oxides. This will permit the improvement of the performance of mid-spectrum IR detectors.

31. Relative Humidity Indicator - Research is required to develop a rugged, sensitive, DC-driven relative humidity indicator. In particular it should have an accuracy of $\pm 0.1\%$ relative humidity in the ranges of 0-4% and from approximately 95%-105%. The device should exhibit low impedance characteristics and be capable of automatically recovering from the supersaturated region; required by 1980.

32. Spacecraft Laser Rotation Sensor - Develop a sensitive rotation rate sensor consisting of a fiber optical coil with a small laser coupled into each end. Rotation about the coil axis alters the relative laser frequency in proportion to the angular frequency. Research is required on the basic concept and alternatives.

MISCELLANEOUS

33. Information and Computer Science - Despite NASA expenditure of an estimated 2×10^8 dollars/yr on software, there is no centralized NASA recognition of computer and information science as disciplines that have the potential of producing large agency benefits from small advances in understanding. Basic research in these disciplines, such as development of specialized algorithms, machine perception, man-machine interactions, etc., should be coordinated and funded out of a central office. This coordination could provide large near-term savings and certainly has a direct relation to potential

applications of great importance to NASA in the 80's and 90's.

34. Brain-Machine Data-to-Information Process Synthesis -

Studies are required to synthesize the results of extensive on-going non-NASA supported research on the mechanisms by which the human brain organizes and compresses large input data rates by a factor of as much as 10^6 , with the goal of evaluating the possibilities of developing flight instruments capable of similar bandwidth compression. Such instrumentation would be capable of extracting from very high data rate systems only the most significant information, thus permitting considerable reductions in communication system bandwidths.

35. Boundary Layer Transition - Current theories are generally inadequate in their prediction of the transition of a boundary layer from laminar to turbulent flow. Particular parameters of interest include not only the onset of transition but also prediction for hydrodynamic and thermal characteristics within the boundary layer. The need is to develop, through analysis and experimentation a reliable predictive tool. Environments of interest cover the full span of potential conditions for entry into the earth's atmosphere.

36. Molecular Reactivity Studies - Measurement of reactive cross section of the interaction between a translationally, vibrationally and rotationally characterized molecular beam with surfaces in space is proposed. A movable mass spectrometer will detect the angular dependence of product fluxes. Utilizing space as a pump, the experiment can be simplified

by achieving a low background pressure.

37. Energy Exchange Between a Fluctuating Magnetic Field and a Turbulent Conducting Fluid - Theoretical and experimental studies on this subject are required to evaluate whether energy could be extracted from fluctuating magnetic fields, particularly near planets, for spacecraft power or propulsion. Particular emphasis should be placed on the efficiency of energy extraction as a function of field-fluid interaction times, and field and turbulent fluid parameters. Promising results could lead to the requirement for space tests in the far term.

38. Fluid Momentum Generator - Demonstrate a fluid rotor momentum generator for space use utilizing a low viscosity magnetic fluid driven by a linear induction motor. Both fluid rotor generators and magnetic fluids have been demonstrated separately. Research on the combination is required to confirm the concept and demonstrate its low torque jitter, reliability, and low cost.

B. USER GROUP MISSION NEEDS

The working group's responsiveness to the basic research needs of the users centered around five primary resources:

(1) presentations during the first two days of the workshop, (2) OAST Summer Workshop Overview Report, (3) Outlook for Space documents, (4) 1973 mission model and (5) technical discussions with users during the workshop.

Of these five sources the one which proved to be the most fruitful in terms of pure exchange of information was the round table discussions with the users. A very valuable result of this workshop is that it has provided a vehicle for two groups of people, basic researchers and mission managers, who rarely have the opportunity to interact in a structured forum, to meet and discuss at length science problems and possible solutions. The working group believes that future sessions of this type could prove to be of great benefit to NASA's overall Research and Technology programs.

The three documents were used by the working group to quantify user basic research needs. These sources were examined in committee on a mission-by-mission basis and the needs identified. These needs were categorized into science disciplines which were then cross-referenced to the missions in order to obtain some measure of the frequency of citation of the disciplines. A listing of these science disciplines, in terms of the sources from which the needs were identified and the missions to which the needs are applied, is shown below.

QUANTUM ELECTRONICS/LASERS AND OTHER DEVICES

1. OAST Summer Workshop Overview Report

- a. OSS Physics and astronomy -- large structures in space
- b. OSS Physics and astronomy -- improved optical techniques
- c. OSS Physics and astronomy -- improved sensors
- d. OSS Planetary-Navigation, guidance and control
- e. OSS Planetary-Deep entry outer planet probes
- f. OSS Planetary-Comet and asteroid rendezvous
- g. OSS Planetary-Mars surface sample return
- h. OSS Launch Vehicles
- i. OSS Lunar-Improved earth-bound remote sensing
- j. OA Communications
- k. OA Earth and ocean physics - supporting technologies
- l. OA Earth and ocean physics - technique development
- m. OA Space processing
- n. OA Earth observations - earth resources
- o. OA Earth observations - weather and climate
- p. OA Earth observations - pollution monitoring
- q. OMSF - Developing Space Occupancy

2. Outlook for Space

- a. Large scale, reliable microcomponent utilization
- b. Precision Navigation
- c. Data interpretation

CRYOGENIC SYSTEMS TECHNOLOGY/NORMAL CRYOGENS AND SUPERFLUID HELIUM

1. OAST Summer Workshop Overview Report

- a. OSS Physics and astronomy - Improved sensor
- b. OSS Planetary - Deep Entry outer planet probes
- c. OSS Planetary - Comet and asteroid rendezvous
- d. OSS Launch Vehicles
- e. OA Communications
- f. OA Earth and Ocean physics - technique development
- g. OA Earth and Ocean physics - supporting technologies
- h. OA Earth observations - Earth resources
- i. OA Earth observation - pollution monitoring
- j. OMSF Developing space occupancy

2. Outlook for Space

- a. Instruments and Sensors

SUPERCONDUCTING QUANTUM DEVICES AND DETECTORS

1. OAST Summer Workshop Overview Report
 - a. OSS Physics and astronomy - High density low power data
 - b. OSS Physics and astronomy - Improved sensor
 - c. OSS Planetary - Navigation, guidance and control
 - d. OA Communications
 - e. OA Earth and Ocean Physics - Supporting technologies
 - f. OA Earth and Ocean Physics - Technique development
 - g. OA Space processing
 - h. OA Earth observations - Earth resources
 - i. OMSF - Developing space occupancy
2. Outlook for Space
 - a. Large scale, reliable microcomponent utilization
 - b. Autonomous Spacecraft and Vehicles
 - c. Instruments and Sensors

REMOTE SENSING

1. OAST Summer Workshop Overview Report
 - a. OSS Planetary - Venus lander mission
 - b. OSS Lunar - Improved Surface mobility
 - c. OSS Lunar - Improved Earth-based
 - d. OMSF - Developing space occupancy

NUCLEAR ENERGY

1. OAST Summer Workshop Overview Report
 - a. OSS Planetary-Outer planet orbiters
 - b. OSS Planetary-Comet and asteroid rendezvous
 - c. OSS Launch Vehicles
 - d. OMSF - Developing space occupancy
2. Outlook for Space
 - a. Nuclear space power and propulsion
 - b. Advanced propulsion

PHOTO-INDUCED REACTIONS

1. OAST Summer Workshop Overview Report
 - a. OSS Launch Vehicles
 - b. OSS Lunar Programs - Improved Geochemical/Geophysical
 - c. OMSF - Developing space occupancy
 - d. OA Space Processing

FAULT TOLERANT THEORY

1. OAST Summer Workshop Overview Report
 - a. OSS Planetary-Outer planet orbiters
 - b. OSS Launch Vehicle
 - c. OMSF - Developing space occupancy

ARTIFICIAL INTELLIGENCE

1. OAST Summer Workshop Overview Report
 - a. OSS Planetary-Outer planet orbiters
 - b. OSS Lunary - Improved surface mobility
 - c. OMSF - Developing space occupancy
2. Outlook for Space
 - a. Large scale, reliable microcomponent utilization

SOLAR-ELECTRIC

1. OAST Summer Workshop Overview Report
 - a. OSS Planetary-Comet and asteroid
 - b. OSS Launch Vehicles
 - c. OMSF - Developing space occupancy
2. Outlook for Space
 - a. Space energy converters

FAILURE PHYSICS

1. OAST Summer Workshop Overview Report

- a. OSS Planetary-Outer planet orbiters
- b. OMSF - Developing space occupancy

BIOENGINEERING

- 1. OAST Summer Workshop Overview Report
 - a. OMSF - Developing space occupancy
- 2. Outlook for Space
 - a. Closed Ecological and Life Support Systems

C. WORKING GROUP RECOMMENDATIONS

1. BASIC RESEARCH EMPHASIS

As we have documented in Section II B above, the five basic research areas detailed below clearly emerged from our study of the user's mission needs for the coming decades as those which can potentially make a significant technological impact on NASA's future programs. They are all active research areas in which recent progress and one's own imagination can combine to show their great promise. Some may be more important than others for certain types of missions, but the order in which they are listed here does not reflect a priority rating. In our estimation all should be given increased emphasis (manpower, funding, program direction, and coordination) by the appropriate Headquarters offices.

QUANTUM ELECTRONICS: LASERS AND OPTOELECTRONICS

Ranking research areas by the number of possible future mission needs is, of course, a cost-effective approach. On this basis the general area of quantum electronics clearly headed the list. This, in part, stems from the demonstrated use to which these devices have been applied, but also the many, quite probable applications in the future. The laser, for example, is barely fifteen years old yet its use for fundamental investigations, data processing, materials welding, cutting, and drilling, communications, "smart bomb weaponry" and even in the construction industry is well

known. Of course, the potential DOD and industrial applications are immense and heavy investment is being made by these sectors. One might well question the need then for NASA emphasis of this area. The answer is threefold. First, as will be discussed below, the mission application list of the technology resulting from this research will be quite large. It will be essential for NASA to maintain an excellent corps of scientists, expert in this area, to make this application effective and efficient. Secondly, the goals of DOD and industry in this area are frequently not those of NASA. We have particular simultaneous requirements, such as long life operation, high efficiency (to reduce launch weight for a given laser power output), zero-g operation, multiple (cost effective) use, such as using a laser beam to both transmit power and information, and short wavelength so as to obtain minimum beam divergence and maximum transmission range. Thus it will remain the task of NASA to promote research and technology developments toward these ends. And thirdly, as mentioned earlier, this area is in the "technology youth" stage. Its potential for new and dramatic advances in the research area is high. But the short term usage by NASA could also be high if the "turnover" time of bringing basic research results to technical end product (mission equipment) could be shortened. This will indeed only be the case when an active basic research program in quantum electronics is maintained and properly interfaced with mission needs.

Consideration of the mission needs led the BRWG to

envision many potential applications of lasers and optoelectronic devices. Since we were considering the impact of an emphasis of OAST basic research in this area, many of these applications are far term rather than hardware development. However, they are, in general, reasonable extensions of our present knowledge and, in some instances, space applications of already demonstrated techniques.

The Outlook For Space discusses many missions for the benefit of mankind, for navigation, disaster warning, and global communications, which will require high power (>1kW) broadcast or communications relay satellites. The economic and launch weight disadvantages of the large solar cell arrays necessary for such powers (\$2,000 - \$5,000 and ~ 0.05 kg per watt delivered) has led OAST to examine the possibility of supplying power sequentially to such satellites by means of a laser beam originating from a ground-based or a geostationary orbit nuclear-powered laser. Mission analyses indicate certain advantages even with near-term infrared lasers. With increased emphasis in the area of the development of efficient, shorter wavelength lasers, this technique may well lead to significant cost reduction and, in fact, enable new missions. This beamed power may also be used to energize a high specific impulse rocket. Finally, laser energy transmission may prove to be a viable alternative to the extensive (1 km antenna diameter, etc.) microwave power transmitter under consideration in the Satellite Solar Power Station mission.

Many missions, such as the Satellite Solar Power Station,

will require very large structures (tens of kilometers) in space. It will be necessary to accurately assemble them *in situ* and then provide a means, possibly active, for their long term stability. The demonstrated techniques of laser spot and seam welding and drilling, might well be used for in-space construction of these large structures. The large redundancy in such structures may also dictate the use of a computer controlled optical system, possibly with the laser at some distance from the welding site. The small divergency and straight-line propagation (especially in vacuum) of a laser beam can also be used here, as it has on Earth, as a construction theodolite. These properties also can be used to incorporate the laser into an active stabilization system for the completed structure; initial calculations indicate this sensing technique will readily achieve the tolerances specified in the Workshop notes. The necessary orientational stability of some of these structures (~ 0.001 arc second) may also be sensed with laser gyros. Finally, some missions contemplate two or more of these structures, separated by distances in excess of 2×10^6 m, as part of a long baseline interferometer. The separation between these elements must be known to about one part in 10^8 . Again, rough calculation indicates presently used laser ranging techniques can be used.

A large fraction of the missions involve sampling of various atomic, molecular, or ionic species or measurements of physical properties such as temperature, or electric and magnetic fields. Extensive preliminary laser technology develop-

ment has shown the laser to be ideally suited for such measurements, both in situ and remotely. The recent significant advances in tunable lasers now indicates a larger application of these techniques as well as the ability to monitor many species with the same laser systems. For example, the Atmospheric, Magnetospheric, and Plasmas in Space mission (AMPS) will use a tunable laser to detect both Na and O₃. Such techniques should allow the spatial and temporal mapping of such entities, either looking down to Earth, in the intervening atmosphere or in the immediate shuttle environment. For certain applications, e.g., in measuring planetary atmospheres, it may be desirable to use an orbiting laser in conjunction with a passive detector or retroreflective device which descends through the atmosphere. Future developments should also extend the range of present sensitivity of laser techniques to measure plasma temperatures and electron densities and allow the determination of electric fields (Stark effect) and magnetic fields (Faraday effect).

Many other potential mission applications were seen by the BRWG, such as in large bandwidth data transmission, in space processing of materials, and in high speed computer links and holographic high density data storage. Other areas, such as the up-conversion of infrared images to visible wavelengths or the use of the laser as the local oscillator in a heterodyne IR detection system, also seem tenable based on recent laboratory findings. An intriguing application, "matter beam-
ing," needs further investigation, but could find wide appli-

cation in the far-term missions which put man into space habitats. Preliminary experimental and theoretical work (Ashkin, Bjorkholm, Askarian) has shown the ability to entrain and accelerate atoms, molecules, and small spherical shells in a laser beam by means of radiation pressure. It is conceivable that a space habitat might be supplied from a shuttle-based laser, say, with an essential chemical, such as water, by this means.

It is clear that the opportunities in this research area are significant. The basic research group believes they could be realized with proper support and correct program emphasis and coordination.

SUPERCONDUCTING QUANTUM DEVICES AND DETECTORS

A comprehensive research program should be conducted by OAST that leads to the development of superconducting electronic instruments, circuit elements and sensors having performance characteristics unattainable by conventional classes of instruments and designed to respond to NASA's flight mission needs. Currently the OSS Gyro Relativity Experiment is being developed, probably for an early Shuttle launch, for which superconducting quantum electronic techniques are mandatory; it serves to highlight the great potentiality of this field for many of the forthcoming NASA flight missions, as discussed below. Equally important to this recommended plan is the fact that liquid helium cooling systems, which are, of course, essential to superconductivity, are presently being configured into

several additional early Shuttle flight missions, including the LST, and the Shuttle Infrared Telescope Facility (under study) for infrared sensor cooling, and advanced HEAO for a superconducting magnet cosmic ray spectrometer, plus other specific but longer range scientific flight experiment concepts. In fact it was argued at a recent NASA scientific conference that virtually every desirable future physics and astronomy experiment in or on space can or must utilize cryogenic principles, whether superconducting or not, to achieve higher sensitivities, lower mechanical and electrical noise, and better dimensional stability.

In the following it will be indicated that the field of superconducting quantum devices is in its youth; it is not an unproven infant, nor is it yet near maturity. Many device concepts have been identified, others have had their feasibility demonstrated in the laboratory, some have even advanced to the commercial market and surely many have yet to be conceived. NASA's special requirements for high performance flight systems, namely compact, sensitive, low power electronic and sensor systems, emphasize our view that OAST should assume an active role in development of a number of special superconducting quantum electronic instruments and systems.

The superconducting properties which this program seeks to exploit occur at temperatures generally below 10K and include 1) perfect electrical conductivity, which a) permits the existence of truly persistent currents, magnetic flux conservation in superconducting circuits, and the realization of perfect mag-

netic shielding (10^{-8} Gauss demonstrated) and b) can be switched off sharply by heat, electric current, or magnetic field; and 2) the Josephson effects, which are embodied in various electrically stable, carefully fabricated Josephson junctions between two regions of superconducting metal, and which control most of the superconducting quantum electronic processes which we see to be of importance to NASA's programs.

Josephson junctions can carry a dissipationless current up to some maximum in the range of 10^{-2} to 10^{-6} ampere; the weakness required depends on the application. They respond to applied voltages by oscillating with a well defined frequency ($4.83593420 \times 10^{14}$ HZ/V); the inverse process results in signal detection. Josephson junctions are also extremely sensitive to magnetic flux, resulting in useful interference effects within the junction itself. A simple loop of superconductor containing a Josephson junction is a Superconducting Quantum Interference Device (SQUID). SQUIDS are sensitive to magnetic flux, whether ambient or coupled in from an external stimulus, and are capable of linear response to it over the frequency range from pure D.C. to at least 1 GHz. A particularly important feature of SQUIDS is that they possess intrinsic noise which is much lower than is seen in conventional electronic devices, e.g., the noise temperature of a SQUID is of the order of 10^{-3} K or better compared with perhaps a few K (the operating temperature) for an advanced conventional infrared sensor. SQUIDS are used for magnetometry, DC and RF meteorology, detection mixing and amplification of electromagnetic signals, noise thermometry and computers.

A comprehensive list of quantitative examples of superconducting quantum devices already demonstrated in the laboratory which will surely impact NASA's future space missions, is beyond the scope of this document. We will instead give three illustrative examples covering the areas of sensitive magnetometry, infrared sensing, and computers.

A SQUID magnetometer is being developed for the readout element for the cryogenic gyroscope which is the heart of the OSS Gyro Relativity Experiment. In order to achieve the required sensitivity the Josephson junction in the SQUID is in the form of a so-called microbridge. The loop and the junction are a thin, narrow film of superconducting niobium, the loop being 10^{-4} m wide by perhaps 2×10^{-7} m thick. At the position of the microbridge the film thickness is reduced to 10^{-8} m, and its width is reduced to 5×10^{-7} m or less (over a comparable length). Important technologies which are applied to this problem, include advanced thin film techniques to produce undergraded, ultrathin niobium films, and a new, powerful technique known as Electron Beam Lithography (EBL) to produce the bridge constriction, which is narrower than the wavelength of visible light. In EBL the highly focused beam of a modified scanning electron microscope is controlled by an analog or computer-generated digital signal, to expose an electron sensitive material to the proper configuration, similar to conventional microcircuit photoresist techniques. Other superconducting phenomena required in the gyro include the weak, spontaneous, persistent magnetic field (London moment) generated by a thin niobium film

on the spherical gyro rotor, and the essentially perfect magnetic shielding due to a superconducting enclosure around the gyro.

In the area of infrared sensors both superconducting bolometers and frequency sensitive detectors have been successfully used, and a new concept of great promise has been advanced recently. It has been predicted that a very closely packed one or two dimensional array of Josephson junctions should be capable of coherently radiating and detecting radiation out to perhaps millimeter wavelengths with an efficiency which varies as n^2 , rather than n . At the same time the narrow band frequency of such a "superradiant array" can be controlled by a simple voltage bias. The prediction has been confirmed for arrays of two and three microbridge elements; a very high potential exists for the achievement of high resolution, high sensitivity detectors, tunable over a wide frequency band.

Speed limitations in conventional computers result from element switching times and packing densities. The latter factor impacts maximum power dissipation. Josephson junction switching times are presently down to a few tens of pico-seconds at power dissipations of a few microwatts per junction. As described above, the basic techniques for very high density packing of very small junctions are advancing; they should receive particular emphasis. It is expected that the relatively near future will see the advent of superconducting computers with characteristics eminently suited for NASA's space mission needs.

Many other high performance superconducting device concepts

have advanced rapidly in the twelve years since the first successful Josephson effect experiment was conducted. Very high frequency mixing, efficient parametric amplification, super stable and spectrally pure microwave oscillators, and very broadband pulse transmission lines with low attenuation are a few of these. It is exciting to consider a flight mission system carrying a liquid helium dewar which contains many or all of the primary experiment sensors, the precision pointing and navigation components, the compact, high rate data processing components of the communication apparatus, all utilizing the powerful instrumentation techniques of superconductivity.

In conclusion, it is recommended that OAST address itself to the problem of providing at an early date a comprehensive family of high performance instruments utilizing superconducting quantum properties, and configured to solve NASA's particular mission problems.

CRYOGENICS SYSTEMS TECHNOLOGY

The users have indicated the need for liquid helium dewars, particularly for superfluid helium (below 2.2K), for both near- and far-term missions. These will be outlined below. In addition, the availability of such dewars will be essential to the host of superconducting devices, such as gravimeters, detectors, and computing elements, which were discussed in the previous section of this report.

It may appear odd that a "technology" is listed as one of the areas of emphasis suggested under basic research. However,

it was evident to the committee that the problems associated with the design of superfluid helium dewars for space are sophisticated properties, of both zero-g and the fluid, which are not too familiar to cryogenic engineers. Thus, it will be necessary for either basic research scientists to perform what are usually engineering functions or that they work intimately with cryogenic engineers. Certainly, for example, the future needs for ultralow temperatures in space furnished by $^3\text{He}/^4\text{He}$ dilution will require active participation of scientists for the refrigerator design.

The unusual properties of superfluid helium that bear on space-dewar design are:

1. Superfluid helium will by itself move to a region of higher temperature, and while ideal for cooling detectors and for cryogen transfer, this property causes the superfluid to "crawl" out the ventpipe. Porous plugs depending on this exotic property have been designed to prevent such loss, but require testing in space.

2. Superfluid helium has essentially zero viscosity and can undergo complicated thermal-mechanical oscillations. Consequently, mechanical oscillations can build up over long periods of time, causing difficulties in spacecraft pointing.

3. Superfluid helium can exist on a solid surface in the form of a submicroscopic film in which the helium (and thus heat) can flow. Nothing is known about the thermal transport in the thick films expected in weightlessness.

4. The very low surface tension of superfluid helium, to-

gether with its complicated thermomechanical effects, makes it difficult to predict the exact distribution of weightless superfluid helium in a dewar. This affects spacecraft pointing, thermal transport, and venting.

The need for space-qualified cryogen system technology is evidenced by the following summary of specific mission needs:

(i) Infrared Astronomy Satellite (IRAS)

Proposed by JPL in 1971 and currently under study with OSS Explorer Program funding by a scientific team supported by the Dutch and GSFC. A survey of the complete sky in the far infrared in preparation for precision astronomy by the Large Space Telescope and Shuttle Infrared Telescope Facility. The original JPL proposal called for sensor temperatures below 2.2K to permit use of a bolometric sensor to view wave length from 100 to 1000 μm . In the absence of space-proven superfluid technology, it now appears probable that sensors operating at 8 to 10K, limited to wavelengths less than 100 μm , will be flown.

(ii) Gyroscopic Test of General Relativity (GTGR)

Sponsored by Office of Space Science, under development of Stanford University and MSFC. Precession of a high precision gyroscope relative to the fixed stars will be compared to predictions of theory. Superfluid temperatures ($T \sim 2.2\text{K}$) are needed for the necessary temperature uniformity. Superconductive devices are also needed for gyro suspension, gyro position readout and magnetic shielding.

(iii) Large Space Telescope (LST)

OSS sponsored under study by MSFC and GSFC. Basically, the LST is an ultraviolet telescope but the IR community has requested provision of IR capability. Sensor temperatures as low as 4.2K have been requested.

(iv) Shuttle Infrared Telescope Facility (SIRTF)

Sponsored by OAST, under study by ARC. System study by Hughes Aircraft Co. in progress. This facility is specifically dedicated to IR astronomy, with higher accuracy, more flexibility, wider bandwidth and higher sensitivity in the IR than the LST. Sensor temperatures as low as 1°K have been requested by scientists.

(v) Superconducting Magnetic Spectrometer for High Energy Astronomy Observatory, (HEAO)

Sponsored by OSS, being developed by the University of California at Berkeley for an advanced HEAO mission. A pair of large, high field, superconducting magnets at 4.2K will be used to deflect high energy cosmic rays for charge and momentum analysis.

Summary

<u>Mission</u>	<u>Temperature</u>	<u>Technology Needed</u>	<u>Flight</u>
IRAS	2.2K	1977	1979
GTGR	2.2K	1978-79	1982
LST	4.2K (?)	1978	1980-81
SIRTF	1.0K	1979 (?)	1982 (?)
HEAO	4.2	1980 (?)	1982 (?)

A second group of experiments have been proposed and are under study, although no firm flight dates have been fixed. All require extreme cryogenic temperatures, below 1 degree Kelvin, implying special refrigeration techniques.

(i) Cosmic IR Background

The absolute value, temporal and spatial variations, spectral composition and polarization of the black-body cosmic radiation background are of fundamental cosmological interest, since various models of the formation of the universe may be tested by comparison with experimental results. Measurements in the IR are of special significance, since the peak of the black body radiation falls here. Measurements must be done above the atmosphere with sensors cooled below 2 degrees and preferably as low as 0.3K to increase sensitivity.

(ii) Gravitational Radiation Detection

Sensitivity of a Weber (resonant bar) gravitational radiation detector can be enhanced many orders of magnitude by utilizing an extremely high Q single-crystal sapphire rod operated at 0.01 Kelvin. Magnetic superconducting readout, and operation in the noise-free environment of space are necessary to realize the benefit of the improved Q and sensitivity. The experiment is described in Part IA of this overview, Gravity.

(iii) Equivalence Principle of General Relativity

Einstein's theory postulates that gravitational and inertial

mass are equivalent. Present measurements verify the equivalence to one part in 10^{11} . Use of superconducting suspension and superconducting motion detectors is expected to increase this to 10^{12} on an earth based experiment and to 10^{17} in a space experiment.

Although the thrust of this discussion has concentrated on the near-term need for superfluid helium technology, the working group wishes to emphasize the importance of a continuing program of basic research on normal cryogenics in space. Cryogens have been flown in space for some time. However, they have always existed in a controlled gravitational environment or in a supercritical state. The optimization of existing fluid systems as well as the design of efficient cryogen systems for the future will require advances in the current state-of-the-art.

PHOTO-INDUCED REACTIONS

Light initiates a wide variety of chemical effects. Classed broadly according to their results, the most promising reactions fall into the category of dissociation, synthesis and separation. In the future, increasing use and understanding of optical radiation from lasers, from high temperature fission and fusion reactors and perhaps from the sun, will lead to new reactions and processes. Several concepts which are based on photo-induced reactions may have important applications.

Photo dissociation reactions were the first observed and are the most numerous class of photo-induced reactions. This process is an important modifier of the earth's atmosphere since

sunlight dissociates diatomic oxygen which leads to the production of ozone. Photo-induced dissociation is involved in other atmospheric processes and dissociation of solids has been considered as a tracer of stratospheric processes for climate studies. However, detailed understanding and commercial application is very limited.

Photo-induced dissociation of water into hydrogen and oxygen, demonstrated recently at MIT, is sufficiently simple to understand and has broad applications, especially to the production of hydrogen for rocket fuel. The chief advantage of hydrogen fuel comes from its high specific impulse and availability in water. Hydrogen will continue to be used as a high-energy fuel for Shuttle and Centaur. It will be of even greater need when low environment pollution is required. Also hydrogen is being strongly considered as a fuel for advanced aircraft propulsion and for air foil cooling. However, the costs of large volumes of hydrogen are prohibitive and production requires substantial amounts of fossil fuel. Photoassisted hydrogen production could solve the twin problems of hydrogen, cost and availability, and permit its economic use for other purposes both within NASA and also for commercial applications. An efficient method for producing hydrogen may lead to new space uses; for example, (1) for long term fuel storage and safety, carry nonreactive water at liftoff which will be converted to hydrogen when needed for propulsion, (2) instead of dumping excess water as an undesirable waste, dissociate and use the water, (3) use the oxygen generated in water dissociation either for propulsion

oxidizer or for life support.

Experiments on direct photo-dissociation of water have been performed and explained. The more useful phenomena of indirect or photoassisted dissociation of water has been observed and reported for several apparently different chemical systems.

Wrighton, et al, have dissociated water with near u.v. radiation to excite a semiconductor and a small electrical potential (0.25 VDC). Other investigators have reported hydrogen produced by optically induced charge transfer from rare earth ions in solution and by energy transfer from metal atoms. Variations of the processes reported need to be thoroughly investigated.

Efficient production of hydrogen from water will be a new energy technology and may lead to new industries. Cost reductions could produce widespread applications of hydrogen such as fuel for automobiles and aircraft, for cooking and heating, for generating electricity and as a reactant for refining or for producing new synthetic materials.

Other distant NASA applications of photo-induced dissociation may include: (1) planetary geochemical analysis using a laser and mass spectrometer on a rover, (2) preliminary refining in space or on a planet, (3) stimulated evolution of a planetary atmosphere.

Photo-induced synthesis, or dissociation operating by photo-excitation, can produce new materials and new knowledge. Many reactions, which either proceed too slowly or do not occur at all, with standard thermochemistry, can be simulated optically either in the gas phase or where one or more of the reactants is

absorbed on solid surfaces.

Molecules formed in simple exothermic (energy emitting) chemical reactions of free atoms often exhibit a strong vibrational and rotational nonequilibrium excitation, which may sometimes be converted into stimulated infrared emission. Microscopic reversibility requires that such reactions will proceed in the endothermic (energy absorbing) direction more rapidly when the activation energy is deposited in internal energy modes of the reacting molecules.

This process has been astonishingly verified in recent experiments. For example, the stimulation of the endothermic exchange reaction $\text{BR} + \text{HCl} \rightarrow \text{HBr} + \text{Cl}$, using the emission from a pulsed HCl chemical laser, has enhanced the 300°K reaction rate by a factor of 10^{11} ! This results from the excitation of HCl in the zeroth vibration state to the second vibrational state by photon absorption prior to the reaction.

Certainly this new approach to chemistry, wherein a small investment of laser photon energy pre-excites the reactants vibrationally, rather than investing energy inefficiently in a Boltzman distribution of translational energy, portends a new era in chemistry. Reaction rates, and even reaction directions, will be under the fine control of the experimentalist possessing an appropriate radiation source.

NASA may well exploit this new advance, for example, in chemical propellants, closed loop life support systems, and the production of chemicals and isotopes for specific end use which, heretofor, have been too expensive.

Synthesis reactions can be made to take place on a solid surface that provides an energy sink to stabilize the desired products. Such a process is akin to catalysis except with inexpensive materials and free from the problems of poisoning. The use of lasers, reactor radiation and direct solar energy can provide the needed excitation. These photo-induced synthesis reactions are of potential importance to NASA because they may:

1. Lead to exotic new polymers for aeronautics.
2. Replace expensive catalytic processes, especially for the synthesis of fuels and control of pollution.
3. Support direct uses of solar energy for space manufacturing.
4. Be the photo-induced chemistry which occurs on dust grains in planetary and space atmospheres.
5. Be the source or solution of problems of solar-induced shuttle-contamination reactions on spacecraft surfaces.

Separation of isotopes has been induced optically for a few elements. Resonant laser excitation, sufficiently finely tuned, will excite the vibrations of one isotope exclusively. This additional internal energy is used to physically or chemically drive a separation process.

Interest in this field centers on:

1. Reducing the cost of isotopes for auxiliary space nuclear power.
2. Separating radioactive wastes for ultimate space disposal.

BIOENGINEERING

A particularly intriguing topic which the working group

discussed at some length was that of the impact of space on plant life and how mankind can benefit from this impact. Although this would most reasonably fall outside the responsibility of OAST research programs, the working group believes that the potential for exciting research is so great that the subject deserves mention in this report. It should be noted that none of the members of the working group have direct research experience in this area. However, our general scientific inclinations, as fortified by the Outlook For Space documents and the OMSF user presentation, have led us to strongly recommend this area for future research.

The most important issue to be addressed initially is whether plants are capable of completing their life cycle in space. Some work has been done in the short-term, but the long term effects of radiation and reduced gravity have not been defined. Once this capability has been established, a basic research program on plant growth dynamics could be started. The ultimate objective of this work would be an assessment of various radiation and gravity conditions and to define when maximum plant food yield is realized. In addition to providing a unique environment, space possesses isolation that can be exploited to carry out experiments that might prove dangerous to conduct on earth. For example, the selective mutation of species through various means, such as lasers, have been conducted on earth, but not without considerable concern for possible harmful effects. By sealing species in containers and flying them into space, such experiments could then be done in isolated chambers putting poten-

tially harmful species in quarantine.

The fundamental drive behind this research is its application in space. Integration of food plants into a closed, fully recycling life support system, which man would be a part of, would significantly extend the range of manned space exploration. Certainly the feasibility of the lunar or space-based colony missions would be enhanced if they did not have to rely on the resupply of expendables from earth. Because the length of time required of a demonstration for proof of concept is relatively great and the necessary amount of basic research is substantial, it is important that work be initiated at an early date.

Perhaps the most important application of this research could be terrestrial problems. In recent years the seriousness of feeding the world's ever expanding population has received international attention. This concern has been amplified by an incidence of poor weather and disastrous floods which have shortened food supplies and caused famines that have taken their toll in human lives. Certainly, breakthroughs are needed to increase man's ability to feed himself. The research done on plants in space will provide, in general, a better understanding of plant dynamics that would result in more productive terrestrial species. More speculatively, in the far future one can even imagine space farms located at the earth-moon liberation points which would be solely used to generate ultra high yield food. Manned by a minimum number of technicians, automated for a continuously regulated climate and fitted with processors to dehydrate crops, the farms could provide a non-interrupted flow

of food to this earth.

In summary, research on plant life in space offers the possibility of space as well as terrestrial benefits. The results could have an impact on man's survival on earth as well as his ability to satisfy the instinct to explore new worlds. Although the near-term applications are of the most immediate concern and appear the most plausible, the possibility in the far future cannot help but stimulate man's imagination.

2. MISSION NEEDS/RESEARCH INTERFACE

NASA Offices are conducting missions which could receive particular benefit from existing OAST research and technology programs. The working group strongly recommends that a mechanism be implemented to ensure timely and cost-effective support of mission office needs by OAST programs, both at Headquarters and Center management and the working levels.

While it is true that meaningful support must ultimately take place at the working level, overall coordination by headquarters management must occur to maintain balance, assure the proper allocation of resources, and most importantly, to keep OAST responsive to user needs while at the same time assuring that user requirements not thwart the innovative and creative efforts that lead to the enabling research and technology for the radically new missions that constitute NASA's future. Just as important, is the need for management to see to it that the research and technology required by the users are ultimately successfully adapted into user programs and missions. To properly carry out these functions of management is expensive in time and money, and is often overlooked or played down since the "product" of these functions is not easily recognized. Nevertheless, the appreciable cost of investment in these functions, we believe, will in the end result in great cost savings for the agency.

The Basic Research Group has considered many possible ways of carrying out these suggestions. For example, one would be

for the mission offices to set out their research and technology needs as Specific Objectives. A Division in OAST, acting as the interface between OAST and the mission offices, would act with the other OAST Division Directors to reformulate those needs, which they feel that they could reasonably meet, as objectives for the Divisions. The interfacing Division would then ensure that the results of the OAST work were satisfactorily embodied in the user programs. This would be a dynamic process since both the user needs and the OAST capabilities would change in time. To assure coordination at the working level, conceivably the interfacing division could accept and manage RTOP's jointly funded by OAST and the mission offices.

There are obviously many difficulties associated with this and other schemes which we have considered. However, the potential benefits accruing to both the mission offices and OAST justify a continued study and final resolution of this interface need.